MANUAL OF MEDICAL RESEARCH LABORATORY

WAR DEPARTMENT = = AIR SERVICE
DIVISION OF MILITARY AERONAUTICS
WASHINGTON, D. C.

U. S.

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MEDICAL RESEARCH LABORATORY.

W. H. WILMER, *Colonel, M. C., N. A.*

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1 **Physiology:**

EDWARD C. SCHNEIDER, *Major, Sanitary Corps, N. A.*

2 **Psychology:**

KNIGHT DUNLAP, *Major, Sanitary Corps, N. A.*

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PREFACE.

Though the principles of aeronautics were clearly enunciated by Samuel Johnson 159 years ago in his Rasselas, Prince of Abysinia, it was not until within the last decade that air flights began to be practical. During these years infinite time and thought have been spent upon the machine. The pitch of the screw, the angle of attack, the stream line, the admixture of gasoline and air, etc., have all been studied with mathematical accuracy.

But the value of the human machine is just beginning to be properly recognized. A slack control wire is not more dangerous than a weak eye muscle, a poor mixture of gas and air is not more serious than a flier with poor adaptive respiration. And a poor compression in the cylinder is not of such vital consequence as a weak heart muscle.

The Laboratory, which is the workshop of the Medical Research Board of the Air Service, investigates "all conditions which affect the efficiency of pilots"; classifies fliers not only according to their efficiency, but also according to their ability to stand diminished oxygen; and instructs Flight Surgeons and Physical Directors in the reactions of the human system to oxygen want.

This manual is the result of the work done in the Laboratory and it is intended for the information and instruction of those who are interested in the medical problems of aviation. In these brief pages it has been impossible to go fully into a subject so new and so large, but it is the earnest hope that the faithful painstaking work of the department heads and their assistants may be of service in stimulating the study of conditions that are of such vital economic, military, and human value.

William H. Wilmer, M. C., N. A.,
Officer in Charge.

Medical Research Laboratory,
Mineola, L. I., July 6, 1918.

ORGANIZATION OF MEDICAL RESEARCH LABORATORY.

In accordance with paragraph 113, S. O. 243, A. G. O., October 18, 1917, the following officers were directed to report to the Chief Surgeon, Aviation Section, Signal Corps, for assignment to duty as members of a medical research board: Maj. John B. Watson, S. O. R. C.; Maj. Eugene R. Lewis, M. R. C.; Maj. William H. Wilmer, M. R. C.; Maj. Edward G. Seibert, M. R. C.

Dr. Yandell Henderson was added to this board in civilian capacity and was constituted chairman of the board.

The powers delegated to the board were as follows:

This board shall have discretionary powers:

(1) To investigate all conditions which affect the efficiency of pilots.

(2) To institute and carry out, at flying schools or elsewhere, such experiments and tests as will determine the ability of pilots to fly in high altitudes.

(3) To carry out experiments and tests, at flying schools or elsewhere, to provide suitable apparatus for the supply of oxygen to pilots in high altitudes.

(4) To act as a standing medical board for the consideration of all matters relating to the physical fitness of pilots.

In accordance with this authority, the board instituted the following departments:

Otology	Lieut. Col. E. R. Lewis.
Cardio-vascular	Maj. James L. Whitney.
Physiology	Maj. Edward C. Schneider.
Psychology	Maj. Knight Dunlap.
Psychiatry and neurology	Maj. Stewart Paton.
Ophthalmology	Capt. Conrad Berens, Jr.

The immediate military problem of classification of aviators was preceded by certain necessary research sufficient to establish basis of such classification.

The present organization comprises the main laboratory at Hazelhurst Field, with 20 branch laboratories at flying schools and ground schools, 8 of which are now in active operation.

Officers are now under instruction at the main laboratory for the remaining stations.

E. G. Seibert,
Lieut. Col. M. C., N. A.
Secretary Medical Research Board.

MEDICAL ASPECTS OF AVIATION.

I.—ALTITUDE PHYSIOLOGY.

In recent years our knowledge of the conditions pertaining to life at high altitudes has been enriched by careful scientific investigations. The majority of these have been carried out on Monte Rosa in Europe and on Pike's Peak in the United States. Further contributions come from studies made in pneumatic cabinets in which the atmospheric pressure can be reduced to any degree corresponding to known heights.

The physiologic effects of altitude on man and other animals have a threefold interest. The purely scientific aspects of the life under conditions of low barometric pressure are themselves deserving of careful investigation. The fact that altitude plays a part in therapeutics and forms a feature of climatology, as applied by medicine, furnishes another reason why the subject should be placed on a rational basis. While the coming into prominence of aviation which requires a man to ascend into the air as the bird, frequently to moderate and sometimes to great altitudes, furnishes a third reason why we should know what constitutes fitness for life in rarefied air. As soon as an attempt is made to interpret the physiologic phenomena of altitude in terms of their causes difficulties arise. The reason for contradictory theories is to be found in the complexity of the factors which enter into the environment at high altitudes. Among the climatic variables are the low atmospheric pressure with its low partial pressure of oxygen, the peculiarities of the sunshine, low temperature and humidity, the high wind, the electric conditions of the atmosphere, and ionization. It has been found difficult to study these factors one at a time, but with the use of the pneumatic cabinet it is possible to eliminate all factors except lowered barometric pressure and also to study the added influence of other altitude factors. The consensus of opinion held is that the physiologic effects noted at high altitudes are due to the lack of oxygen resulting from the lowered partial pressure of oxygen.

It is clearly established to-day that high altitudes or low barometric pressure when first encountered may interfere with the normal workings of the human machine. A sudden disturbance of any sort of the bodily functions is usually manifest by symptons of illness.

Those disturbances brought on by change of altitude cause the so-called mountain sickness, or, better, altitude sickness, the symptoms of which are generally so mild that they may be entirely overlooked by the unobservant. Mankind differs greatly in the power of adjustment to changes of environment. Hence, it is found that mountain sickness befalls some individuals at a lower, others at a higher altitude, but it is also certain that no one who proceeds beyond a certain elevation—the critical line for him—escapes the malady. An elevation of 10,000 feet or even less might provoke it in some, others may escape the symptoms up to 14,000 feet, while only a very few, possessed of unusual resisting power, can without much distress venture upward to 19,000 feet. The symptoms of mountain sickness depend not only on the nature of the individual and his physical condition, but also on various intricate contingencies, especially on the amount of physical exertion made in ascending; that is, on whether the ascent is performed by climbing or by passive carriage on horse, on railway train, or in an aeroplane.

There are two forms of mountain sickness; the acute and the slow. The acute, due to going too far beyond the individual critical line, breaks out suddenly on entrance into the rarefied air; the slow manifests itself later and other debilitating causes besides the barometric depression often contribute to produce it.

The acute form is characterized by a rapid pulse, nausea, vomiting, physical prostration which may even incapacitate one for movement, livid color of the skin, buzzing in the ears, dimmed sight, and fainting fits.

In the slow form of mountain sickness, which may be called the normal type, the newcomer at first complains of no symptoms. In fact, when questioned he says he feels fine. Occasionally he may report that on stooping over and raising himself up again, he feels dizzy and has a visual sensation of blackness. Even at this time on examination there is found blueness of the lips, edges of the eyelids, gums, and under the finger nails. Some hours later he begins to feel "good for nothing" and disinclined for exertion; to express it differently, he finds that he feels somewhat weak and exhausted. He goes to bed and has a restless and troubled night and wakes up next morning with a severe frontal headache. Many find that the headache begins to develop toward evening or during the night of the first day. Following it there may be vomiting and frequently a sense of depression in the chest. The patient may feel slightly giddy on arising from bed and any attempt at exertion increases the headache which is nearly always confined to the frontal region. On examination the face may be slightly cyanosed, the eyes look dull and heavy and there may be a tendency for them to water. The tongue is furred, the pulse is nearly always high, being generally in

the neighborhood of 100 or over. The temperature is normal or slightly under. The patient often feels cold and shivery. All appetite is lost, some have diarrhœa and abdominal pain. A tendency to periodic breathing is observed in many and physical exertion is accompanied by great hyperpnoea.

There are wide divergencies from this slow or normal type of mountain sickness. Dr. Ravenhill has grouped these into two classes, (1) those in which cardiac symptoms, and (2) those in which nervous symptoms predominate. Neither is common. The cardiac type is well illustrated by one of Dr. Ravenhill's cases. An English gentleman in the Andes Mountains ascended from sea level to 15,400 feet in 42 hours. Three years before he had lived at the same altitude for a period of three months and had been in good health the whole time. He seemed in good health upon arrival; he kept quiet, ate sparingly, and went to bed early, but awoke the next morning feeling ill with symptoms of the normal type. Later in the day he began to feel very ill. In the afternoon his pulse rate was 144, respirations 40. Later in the evening he became very cyanosed, had acute dyspnœa and evident air hunger, all the extraordinary muscles of respiration being called into play. His heart sounds were very faint; the pulse irregular and of small tension, thus presenting a typical picture of a failing heart. The condition persisted during the night; he coughed up with difficulty and vomited at intervals. He was sent down on an early train the next morning. At 12,000 feet he was considerably better and at 7,000 feet he was nearly well. Dr. Ravenhill thought that he would have died had he remained another day.

The nervous type of mountain sickness in its simplest form consists of the feeling of a nervous excitation and buoyancy. Some feel as though they are being lifted into the air as by a balloon. There may be a tendency to twitching of the lips and trembling of the limbs. In severe cases these may lead on to violent spasmodic movements of the limbs and even convulsions. Vertigo may be a prominent symptom, though it is very rarely pronounced.

The symptoms of mountain sickness persist for one, two, and three days and then gradually disappear as the adaptive reactions to high altitude occur. The action of gradually developing want of oxygen at very high altitudes is very insidious as dangerous effects may develop with a dramatic suddenness. Two now historic experiences illustrate this. In 1862 the well known meteorologist, Glaisher, and his assistant, Coxwell, ascended in a balloon. Glaisher first noticed at an altitude of about 26,000 feet that he could not read his instrument properly. Shortly after this his legs were paralyzed and then his arms, though he could still move his head. Then his sight failed entirely and afterwards his hearing and he became unconscious. His

companion meanwhile found that his arms were paralyzed, but that he was still able to seize and pull the rope of a valve with his teeth—this permitted gas to escape—so that the balloon descended. As Glaisher recovered consciousness, he first heard his companion's voice and then was able to see him, after which he quickly recovered. The balloon, during the ascent, reached an altitude of about 30,000 feet. The second of these historic experiences is found in a graphic account given by Tissandier, the sole survivor of a party of three in a fatal balloon ascent in 1875.

"I now come to the fateful moments when we were overcome by the terrible action of reduced pressure. At 22,900 feet (320 mm.) we were all below in the car—torpor had seized me. My hands were cold and I wished to put on my fur gloves; but, without my being aware of it, the action of taking them from my pocket required an effort which I was unable to make. At this height I wrote, nevertheless, in my notebook almost mechanically and reproduce literally the following words though I have no very clear recollection of writing them. They are written very illegibly by a hand rendered very shaky by the cold: "My hands are frozen. I am well. We are well. Haze on the horizon, with small round cirrus. We are rising. Crocé is panting. We breathe oxygen. Sivel shuts his eyes. Crocé also shuts his eyes. I empty aspirator, 1.20 p. m., —7 to —11 degrees, barometer 320. Sivel is dozing, 1.25, —11 degrees, barometer 300. Sivel throws ballast (last word scarcely legible)." I had taken care to keep absolutely still without suspecting that I had already perhaps lost the use of my limbs. At 24,600 feet the condition of torpor which overcomes one is extraordinary. Body and mind become feebler little by little, gradually and insensibly. There is no suffering. On the contrary one feels an inward joy. There is no thought of the dangerous position; one rises and is glad to be rising. The vertigo of high altitude is not an empty word; but so far as I can judge from my own impressions this vertigo appears at the last moment, and immediately precedes extinction, sudden, unexpected, and irresistible. I soon felt myself so weak that I could not even turn my head to look at my companions. I wished to take hold of the oxygen tube but found that I could not move my arms. My mind was still clear, however, and I watched my aneroid with my eyes fixed on the needles which soon pointed to 290 mm. and then to 280. I wished to call that we are now at 26,000 feet, but my tongue was paralyzed. All at once I shut my eyes and fell down powerless and lost all further memory. It was about 1.30."

The balloon ascended 28,820 feet and then descended. Tissandier recovered but his companions lost their lives in the ascent. These extreme cases are cited here in order to bring to the attention of aviators the risk in going to extremely high altitudes without oxygen.

THE CAUSE OF THE SYMPTOMS OF MOUNTAIN SICKNESS.

The essential cause of altitude sickness is lack of oxygen. The probability of this explanation was first clearly pointed out by Jourdanet, but it was Paul Bert, in 1878, who first furnished clear experimental proof that the abnormal symptoms and dangers depend on the imperfect aeration of the arterial blood with oxygen. He

concluded that all the symptoms are simply those of want of oxygen. Later observers, however, questioned this conclusion and attributed the symptoms in whole or in part to other causes. Mosso attributed many of the symptoms to the lack of carbon dioxide, while Kronecker has invoked mechanical factors as a cause. The evidence accumulated by more recent workers, both on mountains and in pneumatic chambers, have definitely confirmed Paul Bert's conclusion.

The call for oxygen in the body comes from the active cells of the tissues. It has been evident for sometime that the place of oxidation is in the cells and not in the blood as was formerly maintained. Complete deprivation of oxygen results in asphyxiation and death. The question that naturally arises is; Is the quantity of oxygen taken up by the cell, conditioned primarily by the needs of the cell or by the supply of oxygen? This has been answered clearly; the cell takes what it needs and leaves the rest. Therefore, it is important that sufficient oxygen be available in the blood when the demand is made by the tissues. The rate of flow and the amount of oxygen passing from the blood to the tissues depends on the difference between the pressure of oxygen in the blood and in the tissue. The higher the oxygen pressure in the blood the greater will be the amount of oxygen passing from the blood of the capillaries into the tissues in a given unit of time. Oxygen diffuses from the place of higher pressure to the place of no pressure or low pressure. In the active tissues the oxygen tension is always low and it is usually supposed there is then no oxygen pressure at all inside the cells. The dissociation of oxygen from the hemoglobin of the blood occurs with great rapidity, but it is greatest where the differences in pressure are greatest. It follows, therefore, that the oxygen pressure in the blood must be sufficiently high to supply the needs of the cell in the brief interval of time that the blood is passing through the capillaries.

There are many ways in which the oxygen supply of the body may be reduced. Whatever the method used there will occur compensatory adaptive reactions in the blood, the breathing, and the circulation for the purpose of furnishing the oxygen needed by the cell. Reduction of oxygen available to the tissues might be brought about by blood letting and anemia; by the administration of carbon monoxide or sodium cyanide; by life on high mountains, in a balloon, in an aeroplane at high altitudes, or in pneumatic cabinets at reduced pressure; by the artificial restriction of the free influx of atmospheric air into the lungs; and by artificial pneumothorax. Any of these methods, if carried beyond a certain point, is known to produce death. If, on the other hand, they are only carried far enough to give a mild oxygen hunger, the body will, as a rule, react so as to compensate for the reduction in the oxygen supply.

n blood letting, which produces an artificial anemia, the percentage of oxygen in the venous blood may be reduced from the normal .2 volumes per cent to 4 or even 3 per cent. In animals thus treated both the circulation and the breathing will show compensatory activity. In cases of anemia with a 20 per cent reduction in hemoglobin an increased pulse rate and an increased respiration will be observed. In cases of poisoning with carbon monoxide and sodium cyanide there will likewise be modifications in the blood flow and respiration. Kholer compressed the trachea of rabbits by tying a lead wire around it. The animals recovered from the operation and lived four weeks. Apparently, to compensate for the interference in breathing, there was an increased rate of respiration and heart activity which made good the oxygen needs of the organism. In case of artificial pneumothorax the hemoglobin of the blood has been shown to increase, the pulse rate to accelerate, and the respiration to deepen. We shall discuss later the adaptive changes which fit the human mechanism for high altitudes. These adaptive reactions are also seen in the blood, in the breathing, and in the circulation.

While all of the tissues of the body are sensitive, the nervous tissues are the most sensitive to oxygen want. The adaptive responses to a lack of oxygen are undoubtedly initiated in the central nervous system. Gaser and Loevenhart find that all of the medullary centers in the brain respond in the same way; first, by stimulation, and then by depression.

The more definite adaptive altitude changes disclosed by experiments are: (1) An increase in the percentage and the total amount of hemoglobin in the blood of the body and also associated with this a redistribution of the red corpuscles whereby a reserve supply is thrown into the general circulation; (2) a fall in the lung alveolar carbon dioxide pressure and a rise in the alveolar oxygen pressure, the result of increased ventilation of the lungs due to deeper breathing; (3) a rise in the arterial blood oxygen pressure which provides a partial pressure of oxygen in the blood much above the alveolar oxygen pressure in the lungs; (4) an increase in the rate of blood flow. Each of these adaptive changes clearly assures a more adequate supply of oxygen for the tissues. The blood changes provide for more oxygen in a given unit volume of blood. The greater ventilation of the lungs permits a more thorough saturation of the hemoglobin with oxygen than would be possible if the oxygen pressure in the lungs decreased proportionately with the fall in barometric pressure. The rise in arterial blood oxygen pressure also means a greater saturation of the hemoglobin. The more rapid rate of blood flow raises to a limited extent the oxygen pressure in the blood passing through the tissues. A discussion of these adaptive changes follows:

THE CHANGES IN THE BLOOD OF MAN AT HIGH ALTITUDE.

It has long been known that the effect of life at high altitudes is to cause an increase in the number of red corpuscles per cubic millimeter of blood and an increase in the hemoglobin percentage of the blood. In 1878 Paul Bert predicted that the blood of man and animals living at high altitudes would be found to have a greater oxygen capacity than that of corresponding individuals living at lower levels. He surmised that the cause of this increase in the oxygen carrying power of the blood would be found to be the decrease in the partial pressure of the oxygen in the atmosphere respired. In 1882 he gave an account of some experiments in which the blood obtained from animals living at a high altitude in Bolivia was found to contain a larger percentage of oxygen than did blood taken from animals at sea level. A little later, in 1890, Viault observed the increase in the number of red corpuscles per cubic millimeter of blood in himself and his companions during a three weeks' visit in Peru at an altitude of 14,400 feet. Numerous subsequent observations which have dealt with these phenomena have confirmed beyond question the earlier data. The following figures illustrate the differences observed in mankind living at different altitudes:

(1) The red corpuscles vary at sea level between 4.5 and 5.4 millions per cubic millimeter; at Colorado Springs, altitude 6,000 feet, between 5.5 and 6.3 millions; and on Pike's Peak, altitude 14,110 feet, between 6 and 8.2 millions.

(2) The percentage of hemoglobin at sea level varies between 94 and 106, average 100; in Colorado Springs, 105 to 118, average 110; and on Pike's Peak, 120 to 154, average 144.

(3) The percentage of oxygen capacity in the blood at sea level varies between 17 and 18.7; in Colorado Springs, 20 and 21.7; and on Pike's Peak, approximately 27.4.

Miss Fitzgerald has found that for every 100 mm. fall in atmospheric pressure there is an average rise of about 10 per cent in hemoglobin and that this rise is approximately the same for women and men. There are greater individual variations in the total increase. It is possible that under a pressure greater than atmospheric the hemoglobin would fall below 100 per cent. The observations of Madame Bornstein on animals have apparently shown a decrease in the percentage of hemoglobin when they were exposed to a pressure greater than atmospheric.

Incidentally it is interesting to note that the blood of the people living at high altitudes fails to show an increase in leucocytes, but does show an increase in the lymphocyte index. Thus at sea level this index averages 37; at Colorado Springs (6,000 feet) 42.5; and

on Pike's Peak (14,110 feet) 50. An increase in the number of blood platelets as well as in the specific gravity of the blood has been observed. The following illustrates the increase in specific gravity: At Colorado Springs, 1.067; after six months residence on Pike's Peak, 1.073.

THE SEQUENCE IN THE BLOOD CHANGES DURING A PERIOD OF RESIDENCE AT HIGH ALTITUDE.

The facts so far given are those obtained from the study of people who are acclimatized to the altitude in which they are living. On passing from a low to a high altitude some time is required to react to the low oxygen of the new altitude. On ascending passively to such an altitude as 14,000 feet it has been found that immediately after arriving no change can be detected in the number of red corpuscles and the percentage of hemoglobin. Just when the changes begin has not been determined, but usually within 24 hours a marked increase in both will be present. A rapid increase in the number of red corpuscles and percentage of hemoglobin occurs during the first two or four days of residence; then follows a more gradual increase extending over three to five or more weeks. These changes are illustrated in the following table:

Date.	Havens.		Schneider.		Sisco.	
	Hemoglobin.	Corpuscles.	Hemoglobin.	Corpuscles.	Hemoglobin.	Corpuscles.
Average, Colorado Springs	109	6,024,000	109	5,992,000	113	6,372,000
June 17, Pike's Peak	123	6,872,000	116	6,472,000	120	6,732,000
June 18, Pike's Peak	126	7,024,000	115	6,400,000	125	6,880,000
June 19, Pike's Peak	129	7,160,000	122	6,800,000	126	6,720,000
June 20, Pike's Peak	130	7,292,000	121	6,848,000	122	6,624,000
June 21, Pike's Peak	132	7,200,000	123	6,736,000	130	6,928,000
June 22, Pike's Peak	135	7,296,000	121	6,472,000	133	7,032,000
June 24, Pike's Peak	135	7,248,000	126	6,616,000	134	7,104,000
June 26, Pike's Peak	134	7,000,000	127	6,656,000	131	6,856,000
June 28, Pike's Peak	129	6,840,000	129	6,896,000	135	7,120,000
June 29, Pike's Peak	132	6,976,000	129	6,960 000	....	....

Views differ as to the mechanism by which the changes in hemoglobin and red corpuscles are brought about. These views may be conveniently divided into three main classes: (1) Those theories which insist that the increase in hemoglobin and red corpuscles is real and not merely relative; two explanations of the increase have been proposed: (*a*) that the increase is due to increased activity of the blood-forming organs, resulting in an increase in the hemoglobin and red corpuscles; (*b*) that the increase is due to a lengthening of the life of the corpuscles. (2) The concentration theories, according to which the increase in hemoglobin and red corpuscles per unit volume is due to increased concentration of the blood. According

to this view, the increase in both is only apparent, and there is no increase in the total number of red corpuscles and the amount of hemoglobin in the body. (3) It has been held that the increase in hemoglobin and corpuscles is due to unequal distribution of the red corpuscles. They are supposed to be more numerous in the blood of the capillaries and smaller vessels and less numerous in the large vessels. This view has not been supported experimentally and may be considered untenable. It has further been supposed that there exists in the body a reserve or dormant supply of red corpuscles which is drawn upon at high altitudes. The discussion at issue seems to permit the following conclusion: The initial rapid increase in hemoglobin and red corpuscles is brought about in part by the passing into the systemic circulation of a large number of red corpuscles that under ordinary circumstances at low altitudes are sidetracked and inactive, and in part by a concentration resulting from a loss of fluid from the blood. The more gradual increase in red corpuscles and hemoglobin extending over several weeks is brought about by an increased activity of the blood-forming centers, so that there results an actual increase in the total number of corpuscles and the amount of hemoglobin. The evidence for the above statement can be briefly summarized. Schneider and Havens have shown that abdominal massage and physical exertion at low altitudes cause an increase in the number of red corpuscles and hemoglobin in the peripheral capillaries; while in men partially or wholly acclimatized to a high altitude abdominal massage either does not change or lowers the content of hemoglobin and red corpuscles, and physical exertion fails to cause an increase. This failure to obtain an increase at high altitude may be accounted for on the assumption that the need for oxygen has called into permanent circulation the reserve supply of corpuscles that is present at low altitude. That an actual concentration of the blood occurs during the first few days of residence at high altitude was proven for three subjects by Douglas, Haldane, Henderson, and Schneider during an investigation made on Pike's Peak. One of their subjects had, after a few days of residence, about a 15 per cent increase in hemoglobin and a total blood volume 10.8 per cent less than at Colorado Springs (altitude 6,000 feet). Dreyer and Walker, reviewing Abderhalden's data, found that a little less than half of a 25 per cent increase of the hemoglobin in rabbits, that Abderhalden concluded was due to concentration, was actually a result of concentration, while the balance of it was to be explained by a new formation of hemoglobin. That there is also an active new formation of hemoglobin and red corpuscles is indicated by several researches. Thus, Zuntz and co-workers found, on comparing stained sections of bone marrow taken from dogs, one group of which had been kept at sea level and the second at a high altitude, that the latter show

a decrease in fat cells and an increase in the blood elements. This, they concluded, indicated increased activity of the corpuscle-producing centers at the high altitude. Douglas. Haldane, Henderson, and Schneider, by the carbon-monoxide method of Haldane and Lorraine Smith, found that during a residence of five weeks on Pike's Peak (altitude 14,110 feet) four men had a large increase in the total amount of hemoglobin and also an increase in the total volume of blood. Laquer found that dogs deprived of hemoglobin of half of their blood supply regenerated it in about 16 days on Monte Rosa, while at a low altitude 27 days were required for the restoration after a similar hemorrhage.

It has been shown in studies on Pike's Peak that the increase in hemoglobin and red corpuscles for an individual is not the same during several trips and sojourns at that altitude. The increase occurs most rapidly when the subject is in excellent physical condition. If prior to the ascent his life has been sedentary and he is known to be physically unfit the changes will be slow in beginning, and the increase when followed day by day will be moderate or slight. If, on the other hand, the subject has taken regular physical exercise and is in excellent condition or physically fit there will be a decided rise in both hemoglobin and red corpuscles in the first 24 hours spent at the high altitude. It has also been shown that fatigue, induced by walking up a mountain, delays the increase in hemoglobin and red corpuscles. The lesson to be gained from these observations is that physical fitness qualifies the subject to react quickly when under the influence of the low oxygen at high altitudes.

CIRCULATION AT HIGH ALTITUDES.

There has been a great interest in the problem of circulation at high altitudes. Many persons, especially those with weak hearts, have an unwarranted fear of high altitudes because they have been informed that they injure the heart. The early studies have been of a fragmentary nature, the observations being confined wholly to a study of pulse rate and the systolic blood pressure. It has recently been shown that there is an increased rate of blood flow at very high altitudes. This is a compensatory reaction which will insure to the tissues a more adequate blood supply. A more rapid rate of blood flow will raise to a limited extent the oxygen pressure in the blood passing through the capillaries, and so insure better oxidation within the tissues. The recent investigations have included observations on the pulse rate, arterial pressures, capillary pressure, and venous blood pressure. Indirect methods have also been employed with the hope of determining the output of the heart per beat as well as the rate of blood flow through the lungs and other tissues.

THE PULSE RATE.

Of all the circulatory changes due to diminished barometric pressure the acceleration of the heart rate is the most noticeable. The majority of the earlier records are from studies made of men who had undergone considerable physical exertion in climbing a mountain. The fatigue thus induced has obscured the early influence of altitude. Therefore, in order to understand the reaction of the heart it is necessary to eliminate all extraneous modifying influences such as fatigue and cold. Pike's Peak offers an excellent opportunity for such Alpine physiological studies, because men may be carried up passively by railway or in an automobile.

It is generally recognized that at moderately high altitudes, 6,000 to 8,000 feet, or even 9,000 feet, the inhabitants do not show an augmentation in heart rate. There is considerable variation in pulse rate of different healthy individuals at sea level. Thus it was found that athletes in Oxford had rates which may be considered normal that range between 44 and 80. In a study of medical students at Cambridge the range was between 47 and 90. The same limits will be found in men acclimated to the moderate altitudes.

On ascending passively to a high altitude, such as 14,000 feet, there is at first no noticeable increase in the rate of heart beat. What happens after the ascent depends on the condition of the subject. If he has ascended much beyond what has been spoken of as the critical altitude line for the individual an attack of mountain sickness is to be expected. If he has not passed his critical line, or only reached it, his pulse rate will continue for some hours at the tempo common to it at the lower altitude. Any exertion will obscure the altitude reaction; if, however, he remains quiet, by the next morning, even while still in bed, the pulse rate will be slightly accelerated. Each successive morning for three to five days the rate will be found to be somewhat greater than on the previous morning. The following example illustrates the amount of change: Thus one subject who had in Colorado Springs (altitude 6,000 feet) an average early morning rate of 53, had on Pike's Peak the first morning a rate of 58; the second 60; the third 63; and the fourth 66. In those who are influenced by altitude sickness the story is different. The heart accelerates as the attack of mountain sickness comes on, and the early morning pulse rate may have reached its maximum by the first morning. As the attack passes off the heart will slow. An example of this reaction is found in the following subject, who had in Colorado Springs an average early morning pulse rate of 61. He became mountain sick six hours after arriving at the summit of Pike's Peak. His pulse rate the next morning was 89, slowing to 80 the second; to

78 the third; and to 72 on the fifth morning. In men who undergo the exertion of climbing a mountain the pulse rate reaction is quite like that observed in those who become mountain sick. The increase in the heart rate has been found to range from 30 to 74 per cent. The amount of acceleration at high altitudes is determined to some extent by physical fitness. There will be less acceleration in the man who is in the pink of condition, while the augmentation is great in those who had been leading a sedentary life and are physically below par. The daily mean pulse rate for men at high altitudes shows approximately the same proportionate increase as the early morning pulse rate does when compared with rates experienced at lower altitudes. The influence of posture upon pulse rate has been investigated, and it has been established that the heart is not necessarily more irritable to changes in body position at high than at low altitudes. In general it may be said that the heart works at an increased rate in all postures at the high altitude. The amount of increase in the pulse rate differs with individuals. Some men will show at the high altitude, such as 14,000 feet, an acceleration of only a few beats over the low altitude rate, while others show an increase of 10 or more beats per minute.

During a sojourn at a high altitude the pulse rate may show a gradual daily increase for a period of one or two weeks, ordinarily not more than one week. With longer residence there is a tendency to return toward the low altitude rate. It appears that the slowing of the heart takes place as other adaptive changes reach their maximum efficiency. Rarely does the pulse rate return completely to the normal rate of the low altitude.

ARTERIAL PRESSURES.

In recent years stress has been laid on blood pressure findings at high altitudes, the value of which has undoubtedly been overestimated. Just what normal blood pressures are at sea level is a matter concerning which there is the widest diversity of opinion. Janeway states that "in the great majority of young males, 100 to 130 mm. will be found", and names the normal diastolic pressure as from 65 to 110. Faught states that 120 may be taken as the normal systolic pressure in the male at the age of 20 and adds 1 millimeter for every additional 2 years of life. He believes that the question as to what variations from this are normal can not be definitely answered, but suggests 17 mm. above or below, or a total variation of 34. The most satisfactory data on blood pressures, as far as the interpretation of altitude effect is concerned, is that obtained from observations made upon the same men at both a low and a high altitude. Such comparisons have been made on Pike's Peak. Data, accumulated

during a period of more than 5 years in the laboratory at Colorado College in Colorado Springs, show that at an altitude of 6,000 feet the systolic pressure is in the majority of young men less than 120 mm. and falls within the range given by Janeway. The diastolic pressure likewise corresponds to that observed in young men at sea level. We may conclude then that at moderate altitude, normal healthy young men show the same range and distribution of pressures as do young men at sea level.

Many physicians still believe that at high altitudes, such as 14,000 feet, the blood pressure increases simultaneously with the decrease in atmospheric pressure, and they conclude that this increase means injury, especially to the weakened heart. The investigations of more recent years show that this opinion is untenable. The observations on Pike's Peak which extend over a number of years and which were made upon men who ascended the mountain passively show that in those who react well to the altitude the changes were surprisingly slight, in fact, they were so slight that they fall for the most part within the errors of observations. Schneider and Sisco concluded that for many, and very likely the vast majority of healthy men, an altitude of 14,000 feet does not influence the arterial blood pressures. In a certain but as yet undetermined percentage of men this altitude will cause a demonstrable fall, and in exceptional men, particularly those who do not react well to the high altitude, will bring about a rise in the arterial pressures.

During an attack of mountain sickness there will be manifested a disturbance in circulation, as shown by the definite rise in the arterial pressures. Thus in one subject the following changes in pressure were noted during and after an attack of mountain sickness: In Colorado Springs, 6,000 feet, he averaged in systolic pressure 118, and in diastolic 85. On going to the summit of Pike's Peak he was ill with mountain sickness the first three days, during which time his systolic pressure averaged 129, and the diastolic pressure 91. However, by the morning of the fourth day he was decidedly better, in fact, had recovered, and during the next three days his systolic pressure averaged 116, and the diastolic 84. The fear of high altitudes undoubtedly is a result of over-emphasis of the circulatory conditions observed during the early days spent at a high altitude when the organism has not as yet accommodated itself to the new conditions of environment. Certainly after adjustment the blood pressures do not show an important change.

VENOUS BLOOD PRESSURE.

Venous pressures have not received the same amount of attention at either high or low altitudes as have the arterial pressures. It is only in recent years that satisfactory methods of observing venous

pressure have been available. Hooker in Baltimore finds that in healthy men the venous pressure varies or ranges between 2 and 16 centimeters of water. Schneider and Sisco found the same pressures may be considered as normal on healthy young men at an altitude of 6,000 feet. On Pike's Peak they find a marked fall of between 20 and 87 per cent in the venous pressure of healthy young men. The changes in venous pressure occurred slowly, in fact, in some of their subjects the pressure was somewhat higher during the first half day spent at the higher altitude. While the venous pressure was shown to fall, they found the venous supply of blood and the venous pressure remained sufficient at the altitude to give a maximum efficiency of heartbeat.

CAPILLARY BLOOD PRESSURE.

Lombard has shown for low altitudes that the most compressible capillaries disappear at a pressure between 15 and 25 millimeters of mercury. The average capillary between 35 and 45 millimeters, and the most resisting capillaries between 60 and 70 millimeters. On Pike's Peak the capillary pressures were in some men slightly lower than when at an altitude of 6,000 feet, while in others the capillary pressures were unaffected by altitude.

It has been frequently claimed that bleeding from the nose, lips, gums, lungs, and stomach is a common experience at high altitudes and this has been attributed to increased capillary pressure. The above observations show this conclusion to be incorrect. Among the thousands of people that ascend Pike's Peak every summer there occur only a few cases of hemorrhage and these are of the nose only. Such cases are so rare that doubt would be thrown on the usual explanation, even in the absence of positive proof that capillary pressure is not increased with altitude.

THE OUTPUT OF THE HEART AND THE RATE OF BLOOD FLOW.

Attempts made to determine the output of blood per beat from the heart have not been very successful. By use of the recoil method of Yandell Henderson the mass movement of the blood has been studied on Pike's Peak. The observations indicate that the output of the heart is either the same as at low altitude or may be slightly less. It is assumed that the pulse pressure is an index of the heart output per beat. Since it has been shown that the pulse pressure is the same at the high and low altitudes for particular subjects under observation we may be permitted to conclude that the output of the heart is unchanged with altitude. If the pulse rate be multiplied by the pulse pressure and the product be taken as a relative measure of the volume of the blood stream per minute, a marked increase in the circulation rate is indicated for high altitudes.

That the rate of blood flow is increased with altitude has been shown by two researches. Schneider and Sisco used Stewart's calorimeters to determine the rate of the blood flow through the hands. The method determines the amount of heat given off by the resting hand in a given time and indirectly the temperatures of the arterial and venous blood. With these data it is possible to calculate how much blood has passed through the hand in order that it might give off a determined amount of heat. By this method the blood flow through 100 c. c. of hand volume was shown to be from 30 to 70 per cent greater, in six men studied, on the summit of Pike's Peak than in Colorado Springs. Kuhn, on Monte Rosa, also has demonstrated, by calculations made from determinations of the oxygen capacity of the blood, the total oxygen consumption and the pulse rate, that the per minute output of the heart is increased at that high altitude.

WHAT CAUSES THE CIRCULATORY CHANGES REPORTED AND THE INCREASED RATE IN FLOW?

All adaptive changes occurring at high altitudes seem to be for the purpose of supplying a more adequate supply of oxygen for the tissues. If, therefore, oxygen want is the cause of the observed increase in the flow of the blood, it is to be expected that the inhalation of pure oxygen while at the high altitude may so benefit the body as to retard the heart and diminish the rate of the blood flow. Schneider and Sisco found that the breathing of an oxygen-rich mixture while on Pike's Peak slowed the heart appreciably and diminished the rate of the blood flow through the hands; from which we may conclude that lack of oxygen calls forth certain definite circulatory responses in men for the purpose of increasing the rate of blood flow, in order that the oxygen pressure may be sufficient to furnish the tissues with the oxygen needed as the blood passes through the capillaries.

THE EFFECTS OF PHYSICAL EXERTION ON THE PULSE RATE AND THE BLOOD PRESSURES AT HIGH ALTITUDE.

The normal circulatory conditions for the majority of men at high altitudes are an increased rate of heart beat and an unchanged, or slightly lowered, arterial pressure, and a lowered venous pressure. All investigators have found that a more marked increase in the pulse rate occurs during work at a high than results with the same exertion at a low altitude. Just what height must be reached before altitude accelerates the exercise pulse rate has not been definitely determined, but the inhabitants at 6,000 feet show no noticeable exercise altitude effect. Observations on the after-effects of walking for 15 minutes at the rate of 3 and 4 miles per hour, show

clearly that physical exertion accelerates the heart more at a high than at a low altitude and that the influence is disproportionately increased as the amount of work is increased. The effect of the lowered barometric pressure is manifest not only in the greater acceleration of the heart, but in the great extention in the time required for the rate to return to the normal after work has ceased. Furthermore, these altitude reactions are greatest during the first days and become less as the individual becomes acclimated. The arterial pressures will be higher after a given rate of walking at a high altitude than after the same amount of work at a lower altitude. Here likewise the greater the exertion the more pronounced is the influence of lowered barometric pressure. In physically fit men the effect of altitude is much less. The facts show that the heart and the blood vessels undergo a greater strain under exertion at the high than is experienced for the same form of exercise at low altitudes. The excessive response of the circulatory mechanism during and immediately following physical work is greatest during the first days; and descreases, particularly for moderate exertion, as the bodily changes of the acclimatization progress. For persons in excellent physical condition and who have reacted well to the altitude the changes of the acclimatization will permit of moderate exertion without a lowered barometric pressure manifesting itself by the more pronounced acceleration of heart rate and increased blood pressure. The evidence at hand makes it probable that in vigorous work, even in those who are best adapted to the high altitudes, one will continue to get a more pronounced reaction than would occur at a low altitude. In order that the effects of acclimatization may be better understood the following examples of the circulatory effects of altitude are given: Walking for 15 minutes at the rate of 3 miles an hour in Colorado Springs one subject had the following changes: An increase of 11 beats in pulse rate and no change in systolic and diastolic pressures. During the first day spent on Pike's Peak a similar walk accelerated the pulse 34 beats, caused a rise in the systolic pressure of 28 mm., and in the diastolic 4 mm. On the fourth day of residence this amount of work accelerated the pulse only 24 beats, increased the systolic pressure 8 mm., and did not affect the diastolic pressure. This same subject, walking at the rate of 4 miles per hour for 15 minutes in Colorado Springs had the following reactions: Average increase in pulse, 24 beats; systolic pressure, 6 mm.; and diastolic pressure, 1 mm. The first day spent on Pike's Peak, this amount of exercise accelerated to pulse 61 beats, systolic pressure 44 mm., and diastolic pressure 7 mm. On the fourth day the pulse increased 54 beats, systolic 23 mm., and diastolic 4 mm. These observations suggest that it would be best to avoid physical work during the first days spent at very high altitudes.

It is to be expected that living at a high altitude, especially when much physical work is done, will increase the weight of the heart, for all muscular exertion tends to increase the weight of the heart, and the result of the work at high altitudes would accentuate the tendency. Strohl compared the heart of Alpine snow birds living at altitudes ranging from 6,700 to 10,000 with the Moor snow bird, which is not found above 2,000 feet, and found that the average weight of the heart of the Alpine snow bird was about 46 per cent heavier than that of the Moor bird. The hypertrophy of the right was greater than that of the left ventricle. He made one observation of considerable interest, in which he found that the heart of a young Alpine snow bird one and a half months old had the same proportions in weight as that of the Moor snow bird, which suggests that the differences ordinarily observed at the two altitudes are due to the greater circulatory reactions called forth during muscular work at the high altitude.

RESPIRATION AT HIGH ALTITUDE.

It has been known since the researches by Haldane and pupils that the volume of fresh air taken into the lungs per minute during rest is so regulated as to keep the partial pressure of carbon dioxide in the alveolar air practically constant for the individual. Therefore the carbon dioxide content of the alveolar air is taken as an index of lung ventilation. The breathing, however, is dependent on the integrity of a very small area, the respiratory center, of the brain in the medulla oblongata. The reaction of this center is regarded as automatic, and any interference with its supply of properly aerated blood causes greatly increased activity and thereby increased breathing. Carbon dioxide in the blood is the stimulant which excites this nervous center of our respiratory mechanism and maintains its regular action. There is no doubt that slight changes in carbon dioxide in the blood affect the respiratory center. The effects of these changes are rapid and marked when in laboratory experiments with animals all the nervous connections between the lungs and the respiratory center are severed. A decrease in the amount of oxygen in the blood will also affect the respiratory center. It is generally held that the amount of oxygen must be markedly lowered before the respiratory center begins to be stimulated by the decrease in oxygen. For our present purposes, the explanation of the breathing changes at high altitudes, attention may be centered on the carbon dioxide content of the blood and in the alveoli of the lungs. Both the percentage of oxygen and that of carbon dioxide are very constant in the alveolar air in spite of great changes in the amount of oxygen consumed and carbon dioxide given off by the body. Since the volume of fresh air taken into the lungs per minute is so regulated

as to keep the partial pressure of carbon dioxide in the alveolar air practically constant for each individual (at about 40 mm. for adult men at sea level), the alveolar ventilation must vary according to the mass of carbon dioxide given off. Even during muscular work this rule holds approximately true under ordinary conditions. A diminution in the alveolar carbon dioxide pressure has been found to indicate an increase in the lung ventilation, while an increase in carbon dioxide means lessened ventilation and a reduction in alveolar oxygen.

The ventilation of the lungs for people dwelling at high altitudes is greater than that of mankind living at sea level. On going from sea level to an altitude of 6,000 feet, with a fall of about 145 mm. from normal in barometric pressure, the alveolar carbon dioxide pressure is lowered about 4 mm.; and on further ascending to the summit of Pike's Peak (14,110 feet) with an added decrease of about 160 mm. in barometric pressure, the alveolar carbon dioxide pressure falls on an average about 10 mm. more. This is a little more than a 30 per cent decrease and indicates a corresponding increase in the breathing. The full extent of the fall takes about two weeks to develop, and thereafter the carbon dioxide pressure will remain practically steady.

If the same alveolar carbon dioxide pressure were to be maintained on Pike's Peak with a barometric pressure of about 457 mm. that is normal at sea level, there would be a marked shortage of oxygen. This would be true, because a deficiency of oxygen in the alveolar air always runs parallel to the excess in carbon dioxide. If the carbon dioxide pressure remained at 40 mm. while the atmospheric pressure had fallen from 760 to 457 mm., it would amount to a relative increase of about 27 per cent in the carbon dioxide and a similar decrease in oxygen. The partial pressure of oxygen in the alveolar air would therefore be about 50 mm. lower than in the inspired air. Allowing for the pressure of aqueous vapor at body temperature, it is found that the pressure of oxygen in the lungs at the altitude of Pike's Peak would be 36 mm. This is an oxygen pressure which would be found if dry alveolar air contained only 5 per cent of oxygen at normal atmospheric pressure, and it is known that marked symptoms of want of oxygen are ordinarily produced under such conditions. Parallel with the fall of about 13 mm. in the alveolar carbon dioxide pressure on Pike's Peak there occurs a rise in the alveolar oxygen pressure of a little more than 16 mm. so that the alveolar oxygen pressure at that altitude is about 52 mm. This rise in the oxygen above what might be expected when carbon dioxide remains unchanged is due to increased breathing.

On going to a very high altitude the breathing is increased at once and the alveolar carbon dioxide pressure falls correspondingly,

but if the altitude is only very moderate there is at first no effect on the breathing. After some days, however, it will be found that the alveolar carbon dioxide pressure has fallen, indicating that the breathing is deeper. The fall reaches a certain amount and the breathing a certain depth, depending on the altitude, and then ceases. Studies on persons residing permanently at different altitudes show that there is a progressive decrease in the alveolar carbon dioxide pressure corresponding to increase in altitude. For every fall of 100 mm. of barometric pressure there is approximately a fall of 4.2 mm. in the pressure in the alveolar carbon dioxide. There is likewise a progressive fall in the oxygen pressure, but this does not follow exactly the same ratio as the carbon dioxide changes. The following illustrates alveolar air altitude changes:

	Barometer.	Carbon dioxide pressure.	Oxygen pressure.
		Mm.	*Mm.*
Sea-level	760	40	100
6,000 feet	615	36	78
14,100 feet	458	27	53
24,600 feet	312	21	33

That the diminution in carbon dioxide is a response to the diminished oxygen pressure there can be no doubt. If the barometric pressure is kept steady and the oxygen pressure is diminished by lowering the percentage of oxygen, the results are precisely the same as those obtained with changes in altitude.

Since the content of carbon dioxide and oxygen in the lung alveoli give an index of the total ventilation of the lungs in breathing, frequent chemical analyses of the alveolar air during and after an ascent will indicate how much the breathing is increasing. As stated above, the breathing responds at once as an ascent is made, but the changes are not completed for several weeks. The following data will illustrate the rate of change:

	Percentage of gases in alveolar air.		Partial pressure of gases in alveolar air.	
	CO_2.	O_2.	CO_2.	O_2.
Sea-level	5.55	14.08	39.6	100.4
Colorado Springs	6.54	12.94	37.3	73.8
Pike's Peak (14,110 feet)	7.8	....	32.2	....
40 minutes after arrival	7.52	11.38	31.1	47.1
Second day	7.41	11.26	30.7	46.6
Fourth day	7.21	....	....	....
Seventh day	7.21	11.98	29.6	49.0
Twenty-eighth day	6.63	13.08	27.4	54.0

In physiology it is found that the action of gases within the body is determined by the pressure and not by the percentage of gas. The above table shows that the percentage of alveolar carbon dioxide rises with the altitude, but as its partial pressure is determined by the barometric pressure we find that there is a fall in the alveolar carbon dioxide partial pressure as altitude increases. As the partial pressure of carbon dioxide in the alveolar air is about a third less (about 27 mm. as compared with 40 mm.) on Pike's Peak than at sea level, it is evident that the alveolar ventilation during rest for an equal production of carbon dioxide is about 30 per cent greater than on Pike's Peak. Actual measurements show that the volume of air breathed by a subject on Pike's Peak is 27 per cent greater during rest in bed, about 31 per cent greater when standing at rest, about 50 per cent greater when walking at the rate of 4½ miles per hour, and 100 per cent greater during more severe exertion than for similar experiences at sea level. An increase of 30 to 50 per cent in the air breathed when the subject is at rest is not noticeable subjectively. During hard work, on the other hand, an increase of 50 per cent in alveolar ventilation is very noticeable since panting becomes excessive with a good deal of muscular work. During hard work, even at sea level, the depth of breathing is about maximal. Hence the increased alveolar ventilation at a high altitude during exertion implies a corresponding increase in the frequency of breath, with a corresponding increased sense of effort. It is clear, therefore, that at the high altitudes, such as 14,000 feet, there is excessive hyperpnea on exertion. The hyperpnea is probably about three times greater than would be the case with a corresponding exertion at sea level. Walking at the rate of 4 miles an hour at sea level would cause no respiratory inconvenience, but the same work at 14,000 feet causes extreme and urgent hyperpnea. Excessive hyperpnea on exertion persists at 14,000 feet during the entire sojourn, but it becomes less marked after the first day or two.

During inaction the breathing at high altitude is ordinarily modified only in depth. The rate of breathing at sea level varies normally between 14 and 18 breaths per minute. In many men this rate also continues at an altitude of 41,000 feet. During exertion the rate must increase since at sea level for a given exercise the breathing is often maximal. It follows, therefore, that the same exertion at the high altitude, if it increases the total ventilation of the lungs, can only do so by increasing the rate of breathing. The following observations made on Pike's Peak clearly prove the above statement: The subject had breathed when in bed at sea level at the rate of 16.8 breaths per minute, when on Pike's Peak 17.3; on standing at sea level 17 breaths per minute, on Pike's Peak 20; walking at the rate of 4 miles per hour at sea level 17.2 breaths per minute, on Pike's Peak

29; and at the rate of 5 miles per hour at sea level 20 breaths per minute, on Pike's Peak 36.

To explain the fall in alveolar carbon dioxide pressure and the increased ventilation of the lungs at high altitudes it is necessary to consider the changes that occur in the blood. Greater stress was laid by Mosso upon the diminished carbon dioxide in the breath, not because its diminution is of any importance in the breathing, but because this is the reflection of a lowered carbon dioxide pressure in the body generally. Want of carbon dioxide would, other things being equal, affect the affinity of the blood for oxygen. Decreased carbon dioxide alone in the blood would increase the affinity of the blood for oxygen. However, with the increase in altitude it is found that the affinity of the blood for oxygen remains approximately unaltered in spite of the lower carbon dioxide tension. This suggests that as one ascends the carbon dioxide in the blood is replaced by something else which produces an equal effect on the affinity of the hemoglobin for oxygen. A study of the dissociation curve of the blood made by Barcroft at various altitudes indicates that there is an increase in the acid radicals, or a decrease in the bases of the blood. The higher the altitude reached the more marked is the acidosis, but at any given altitude the acidosis and the diminution of carbon dioxide so nearly balance each other that the reaction of the blood remains practically constant. Only a very careful study has been able to show that the increase of acidity is slightly in excess of the loss of carbon dioxide. This would lower the affinity of the blood for oxygen very slightly; but at the same time the change would be sufficient to give the increased stimulation to the respiratory center, which would account for the increased ventilation of the lungs. What acid is responsible for the acidosis in the blood at high altitudes has not yet been ascertained. It was once thought that lactic acid appeared in the blood with the acclimatization to high altitude, but this is not maintained at present. It may be that there is no increase of acid at all, but, rather, a diminution in the amount of alkali present. The fact that the alkalinity of the blood is diminished at high altitudes was first demonstrated by Galeoti in 1903. At that time it was already known that lactic acid is produced by an excessive muscular exertion, as a consequence, no doubt, of a lack of oxygen in the active muscles, and this suggested that lactic acid is formed when the organism experiences the oxygen want at high altitudes. But the excess of lactic acid formed during muscular exertion disappears again within an hour, together with its effect on the alveolar carbon dioxide pressure. If the diminished alkali of blood at high altitudes were simply due to lactic acid formed in excess, we should similarly expect this diminished alka-

linity to disappear and appear rapidly, and would expect similar marked variation in the alveolar carbon dioxide pressure. The increase in acid in the blood and the lowering of the alveolar carbon dioxide, however, require days to develop. Vezar has shown that oxygen want increases the activity of the kidneys, which suggests that oxygen want so affects the kidney that it excretes alkali more freely. It certainly looks as if the blood and the breathing changes were due to some adaptive alteration in the regulation of blood alkalinity. "The fixed alkalinity of the body as a whole, including the blood, is evidently regulated normally by the action of the kidneys, although the liver, by varying the amount of ammonia in the blood, may also contribute to the regulation. A slight and gradual adaptive alteration in what one may call the exciting threshold of alkalinity for the kidneys would explain the reduced fixed alkalinity of the blood in acclimatized persons." The above observations, if correct, indicate that there is a loss of reserve alkalinity among the inhabitants of high altitudes which may place the body at a disadvantage in certain pathological conditions.

OTHER ALTITUDE RESPIRATORY OBSERVATIONS.

Periodic breathing is frequently observed among newcomers at very high altitudes—the type varying in different persons. It may occur in groups of three or four breaths, each succeeding breath being deeper than the preceding one and each group then followed by a pause in breathing; or there may be no pause, the breaths occurring in groups of 6 to 10 in which there is a gradual increase in depth to the mid-point and then a gradual decrease. The periodic breathing often is initiated by muscular exertion and may be started at any time by a few forced breaths or by holding the breath a few seconds. No doubt the spontaneous periodic breathing met with at the high altitudes depends upon want of oxygen in that it has been shown that it may be abolished by the administration of pure oxygen. Periodic breathing disappears in the majority of men as they become acclimated to the altitude.

The ability to hold the breath is decreased at high altitudes. It has been found that when first arriving at 14,000 feet men may be able to hold the breath almost as long as at a low altitude. Day after day, for some time, it will be found that the voluntary effort of holding the breath becomes greater and that the period of holding grows shorter. No doubt the ability to hold the breath decreases as the acidosis of the blood increases.

It is a popular belief that high altitudes increase the size of the chest and the vital capacity. Humboldt, in 1799, claimed to have observed this increase in people of the Andes; and Williams noted the same result after residence in a high mountain resort. With

these exceptions all observers agree that for the majority of persons the low atmospheric pressure alone does not increase the vital capacity. It has been shown that the enlargement of the heart at high altitudes is the result of the greater demands made upon that organ during physical exertion. If the chest should be found larger among the inhabitants of high altitudes it likewise may be explained by the increased demand made upon the breathing during muscular effort. The immediate effect of altitude is to cause a slight decrease in the vital capacity. A comparison made of men, at a low and high altitude, indulging in outdoor sports, would show that the vital capacity and the chest measurements are similar. Use makes the organ, and the size of the chest depends upon the demands made in breathing by physical exertion during the period of growth.

THE OXYGEN PRESSURE OF THE ARTERIAL BLOOD AT HIGH ALTITUDES.

The problem which concerns us here is to determine the forces by which oxygen is transported from the alveolar air of the lungs into the blood. With increasing altitudes the air is reduced and oxygen tension becomes lower and lower. At a height of about 15,000 feet the barometric is little over half that of atmospheric pressure and the oxygen tension, therefore, only about 11 per cent of an atmosphere. As has been pointed out, the presence of man at any considerable altitude necessitates adjustment on his part so that the persistent undiminished oxygen requirement of the body can be satisfied under the enforced changes of atmospheric conditions. Three of the possible means of providing the necessary oxygen have already been discussed. The fourth possibility is still under debate among physiologists. All the symptoms of altitude sickness, due to the diminished barometric pressure, depend directly or indirectly upon the diminution of arterial oxygen pressure and the consequent imperfect aeration of the arterial blood and deficient saturation of its hemoglobin with oxygen.

The passing of oxygen from the alveolar air into the blood of the lung capillaries may be wholly the result of diffusion of oxygen, in which case it would pass from a place of high to one of low pressure. If oxygen passes from the alveoli only by diffusion, the pressure of oxygen in the blood will always be less than, or at the best equal to the alveolar oxygen tension. If the pressure of oxygen in the blood is under certain circumstances, higher than that of the alveolar air there can be no doubt that forces other than diffusion must come into play. This would necessitate an active secretion by the epithelial cells of the lungs. At sea level, during rest, the arterial oxygen pressure is practically identical with the alveolar oxygen pressure. The Anglo-American Pike's Peak Expedition in 1911 made a careful study of the arterial oxygen pressure and found in every case that the arterial oxy-

gen pressure in men on Pike's Peak was much above the alveolar oxygen pressure. The average excess of oxygen pressure in the arterial blood was 35.8 mm.; the mean normal resting alveolar oxygen pressure 52.5 mm.; the arterial oxygen pressure, therefore, 88.3 mm. The alveolar oxygen pressure at sea level is about 100 mm. and that of the blood about the same. At sea level the arterial blood is 96 per cent saturated with oxygen, while on Pike's Peak, if the changes of acclimatization are well established, it is 95 per cent saturated. One subject was examined within an hour after reaching the summit of Pike's Peak by railway. His face had a distinctly bluish color and he suffered somewhat severely from mountain sickness during the ensuing 24 hours. At this time—the time of the experiment—his arterial oxygen pressure was 52.7 millimeters, or only 7 millimeters above the alveolar oxygen pressure. Three days later, when he had become acclimated, feeling perfectly well and with normal color, the arterial oxygen pressure was 81.4 millimeters, or 40.7 millimeters above the alveolar oxygen pressure. These results are very striking and point consistently to the conclusion that in acclimatization to high altitudes the lungs acquire the power of raising the arterial oxygen pressure by actively secreting oxygen.

Certain indirect evidences support this theory of oxygen secretion. It was found on Pike's Peak, on saturating the blood with alveolar air in a saturator, that the blood was noticeably dark in color as compared with the blood when drawn. It is well known that men can live and work at higher altitudes than that of Pike's Peak. In the explorations of the Duke of the Abruzzi in the Himalayas he and his companions climbed to an altitude of 24,580 feet; the atmospheric oxygen pressure saturated in inspiration would be 55.4 millimeters and the alveolar oxygen pressure only 21 millimeters. Blood saturated with alveolar air at this pressure would be less than half saturated with oxygen, which is the percentage found in the arterial blood of animals at the point of death from asphyxia. Nevertheless, at this altitude the members of the expedition felt well and were able to do the climbing necessary in attaining the altitude. The recent advances in knowledge as to the blood gases and the physiology of respiration make it difficult to explain by the simple diffusion theory the reactions above quoted. Haldane and his colaborators have found that at sea level muscular work may furnish a powerful stimulus to secretory absorption of oxygen by the lung epithelia tissue. Therefore one advantage in indulging in heavy muscular work would be to train the lungs in oxygen secretion.

THE VALUE OF THE FACTORS OF ACCLIMATIZATION.

The acclimatization to oxygen want in mountaineers or persons living at high altitudes is evidently attributable to four factors:

The increased breathing, the increased percentage of hemoglobin, the increased rate of blood flow, and the increased oxygen tension in the blood, the result of increased activity of the lung epithelium.

There are varying degrees of susceptibility to want of oxygen among any group of men exposed to low barometric pressure. With a rapidly falling oxygen pressure some persons simply become blue and lose consciousness without the adaptive mechanisms of the body making any evident response. Men who are fortunate enough to possess brain centers sensitive to oxygen want will respond quickly to the stimulus of a lack of oxygen and either escape or have only a mild attack of mountain sickness. On the other hand, those with an insensitive nervous mechanism will fail to respond, or be so slow in doing so that a period of altitude sickness must be expected. This sickness will begin to wane when the adaptive changes begin to be manifest. There are marked individual differences which are no doubt associated in some way with the freedom of the blood supply to the brain. Ordinarily on ascending a mountain the respiratory adjustment occurs first, beginning almost at once; it requires, however, several weeks to become complete. After some delay the blood changes, the increase in the rate of blood flow, and the so-called oxygen secretion manifest themselves. The order of their onset and the rapidity of development will depend on the physical condition of the individual and the sensitiveness of the brain centers to low oxygen.

There is at the start a rapid increase in each of the factors involved, followed by a more gradual continuation of the effect extending over some weeks. The increase in the rate of blood flow and the oxygen secretion by the lungs are developments of the first two or three days spent at the high altitude. The blood changes, while rapid during the first few days, require more than five weeks to reach their maximum value. The changes in the breathing, the blood, and in oxygen secretion are of a permanent character and will not diminish with a prolonged residence at the high altitude. The changes in the rate of blood flow are of a less permanent character; with the acclimatization the pulse rate returns somewhat toward the sea-level values. Undoubtedly the heart is under a greater strain during the early days spent at a high altitude than later, when the adaptive changes have been completed. Physical fitness usually assures an early and rapid response to the stimulating effects of low oxygen at the high altitude. Fatigue and other debilitating causes delay the response and make the individual more liable to an attack of altitude sickness.

The longer the period of sojourn at a high altitude the more permanently fixed become the altitude adaptive changes. This fact has been proven by studies on the after effects of high altitudes in those who return toward sea level. If the sojourn at the high altitude were

of a short duration, only a few days, on returning the blood is restored almost immediately to its normal composition. The breathing likewise at once takes on the normal depth and rate. After a sojourn of five weeks on Pike's Peak the after effects on descending were shown to be present for a period of at least two weeks. At the end of a six months stay at the same altitude the percentage of hemoglobin, number of red corpuscles, total volume of blood, and total oxygen capacity did not alter at once and were at least 10 weeks in being restored to the low-altitude values. The breathing for 24 hours was as great as when at 14,110 feet and then slowly, throughout a period of 10 weeks, decreased to the normal for the lower altitude. The first days after descending, the pulse rate was about 10 beats below the normal for the low altitude, but later accelerated to the normal for the particular altitude.

The study of the after effects indicates that the aviator remains at the high altitudes too short a period of time to secure permanent adaptive reactions which increase toleration of high altitudes. Repeated experiments in pneumatic chambers and with carbon monoxide occasionally have increased in some men the ability to tolerate low oxygen. The experience in aviation indicates that the changes in altitude during flying are made so rapidly that the compensating mechanisms for low oxygen are overworked to a greater or less degree, and as a consequence instead of securing acclimatization to low oxygen a weakening of the adjusting mechanisms occurs, which renders the flier more liable to an attack of altitude sickness.

PHYSICAL FITNESS AND THE ABILITY TO WITHSTAND HIGH ALTITUDES.

The ability to endure comfortably and well high altitudes is dependent upon the ease and the quickness with which the adaptive responses in the breathing, the blood, and the circulation take place. An explanation of the difference in reaction observed among the members of a group of men when at a high altitude is to be found in the degree of individual physical fitness. In persons damaged by disease, overwork, unhygienic living, or weakened by inactivity and by loss of sleep, the power of adjustment is as a rule below par. The normal equilibrium of the body is so nicely adjusted that under usual conditions the physiological balance is largely maintained by adjustments that are made with little or no expenditure of energy. There is a certain range of greater or less breadth through which the external factors of the environment may be varied and yet be met by an automatic adjustment of the physiological processes in the body which will preserve the vital balance of the mechanism. But beyond a certain point, specific for each organism, changes in the external conditions will necessitate more radical alterations which will tax the compensating mechanisms to the utmost capacity in order to pre-

vent disaster. Theoretically the organism which has been called upon repeatedly to make a certain kind of adjustment will be the one most capable of responding when an extraordinary demand is made. The unusual demand made upon the organism at a high altitude is that of supplying the requisite amount of oxygen to the tissues from an atmosphere that provides oxygen at a greatly reduced pressure. An organism that has always been able to supply its oxygen needs without profound or costly changes because the demands for oxygen have never been excessive or the oxygen supply has never been reduced will most likely not readily respond when it meets a shortage of oxygen. In the everyday experiences of life there arises a marked increase in the demand for oxygen during physical exertion. Excessive exertion may, of course, call for so much oxygen that the adjustments of the body may fail to provide sufficient quantity for complete combustion in the muscles. That this is often the case is proven by the great production of lactic acid during physical work. Since physical exertion does increase the demand for oxygen it is to be expected that the organism which has been called upon to do physical work frequently will have acquired marked powers for compensating for oxygen want.

Comparisons made of animals leading a muscularly inactive life with those of a closely related species whose mode of living calls for much running and great physical endurance show certain well-defined differences attributable to muscular action and the call for oxygen. It has been found that the active animal has a heart which relatively is three or four times heavier than that of the inactive animal. Also the rate of the heart beat is much slower—only about a third—the rate of respiration less, the depth of breathing greater, and the percentage of hemoglobin greater in the active than in the inactive animal. Furthermore, the flesh of the active animal is darker in color, due to the presence of a larger amount of myohematin—the substance with marked affinity for oxygen. These differences are undoubtedly adaptive and fit the organism to supply the tissues with the extra amount of oxygen required during exertion.

The adaptive characters found in physically active animals are very like those that appear in the body of man when he follows a regular and consistent course of physical training, and they likewise are characteristics which will permit the individual to tolerate well high altitudes. Comparisons made of athletic and nonathletic individuals show that the athletic, or better, the physically fit persons possess certain physiological conditions of advantage at high altitudes.

In the physically fit the daily indulgence in physical exercise will be found to have increased the percentage and the total amount of

hemoglobin in the blood. With this advantage, if he goes to a high altitude, he quickly responds to the stimulating influence of oxygen shortage by throwing into the circulation the reserve supply of corpuscles and by further concentration of the blood. Consequently the tissues are supplied with blood which per unit of volume is richer in oxygen than it would be if the hemoglobin were less concentrated. In the untrained man there is less hemoglobin, and the changes induced by altitude occur so slowly that he will most likely suffer with altitude sickness because of oxygen want.

In the physically well trained the breathing is slow and deep, while in the untrained it is shallow and rapid. Deep breathing, which can be cultivated by exercise, but not satisfactorily by voluntary attention, ventilates the lungs more effectively than shallow breathing; therefore at a high altitude there is advantage in being a deep breather. It also can be shown that the breathing of the physically fit man responds quickly and well to the high altitude demand for more oxygen, while in the untrained it will be slower in doing so.

At sea level moderate muscular work does not create a great demand for oxygen, but strenuous and prolonged exertion may tax the oxygen-providing mechanisms to their utmost capacity. In order to meet this increased demand for oxygen the lungs may respond by secreting oxygen into the blood. Repeated demands for oxygen secretion would, so to speak, train the lung epithelium for the unusual work. It is suggested that such a reaction by the lungs would be valuable when one ascends to high altitudes, in that the lungs would then immediately begin to secrete oxygen. Oxygen secretion is in the nonathletic type of individual acquired only after several days of residence at a high altitude, but in the vigorous well-trained man it probably begins almost immediately.

As a result of physical training the heart reduces its rate of beating and is less sensitive to changes in posture and to moderate exertion. In the physically fit the heart rate does not increase much on standing, but in the wearied or physically stale subject it increases as much as 44 beats per minute. The vasomotor control of the splanchnic area in man experiences a change of adjustment when the body is moved from the horizontal to the upright standing position. In a robust subject the splanchnic vasotone increases and the blood pressure is raised about 10 millimeters of mercury. In an individual weakened by dissipation, overwork, lack of sleep, etc., the blood pressure tends not to rise, but to fall. Weakness is sometimes shown by a decrease in blood pressure and at other times by an excessive increase in the heart rate.

At a high altitude, especially during the first days of residence, any physical exertion makes a greater demand on the heart than the

same amount of work at sea level. In the nonathletic individual the heart reacts excessively as a result of work, while in men in excellent physical condition the reaction at a high altitude is less and the strain on the heart will, therefore, be much less. A trained heart, like a trained muscle, works more smoothly and easily than the untrained, and therefore endures fatiguing work better than the untrained heart.

Medical experience with the "stale pilot" and the "stale athlete" has shown that as a man becomes stale his pysiological condition reverts to that of the nonathletic type of individual. Staleness is recognized by an increased frequency of pulse, which is also poor in volume and low in tension. There will be distress on slight exertion, accompanied by a rapid rise in the pulse rate, which returns only after a long interval to its former rate. The breathing also frequently becomes shallow and rapid, and the extremities become poor in color and cold because of poor circulation.

Most of the symptoms reported as common among aviators while flying are those that are characteristic of mountain sickness. It has been shown that mountain sickness is not so common among robust as among individuals of sedentary habits of living. We may venture to conclude, therefore, that the man who is in the "pink of condition" as a result of consistent and common-sense physical training will be more resistent to the action of altitude than the untrained or the physically stale man.

Medical experience with "stale" aviators shows a type known as the nervous in which there is poor muscular control over balance movements, fine tremors of the hands and eyelids, greatly increased reflexes, loss of sleep, nightmares, and apprehensive starts with slight noise. The influence of high altitudes on the nervous system has not been carefully studied, but there are those who believe that in persons with poor compensation and an unstable nervous system there is increased irritability or hyperexcitability which may manifest itself in motor, sensory, or psychic spheres, or in a combination of them. Associated with the increased excitability there is increased rapidity of fatigue which finds expression in muscular weakness and diminished physical endurance, as well as failure in adaptability and power of concentration mentally. Such persons complain of a mental unrest, approaching anxiety, and find difficulty in carrying on the usual mental requirements of their occupations. Such a condition may be the forerunner of a simple neurasthenia or a more profound neurosis.

The nervous system is exceedingly sensitive to oxygen want. It is significant, therefore, that in the nervous system arrangements are provided for a free supply of oxygen. The lack of oxygen at high altitudes is felt by all body tissues, but especially by the nervous

tissues. It seems to be established that there is an irritability of the nervous system that may be attributed to diminished oxygen supply by reason of a failure on the part of certain individuals to compensate adequately to lack of oxygen when at the high altitude.

Relation of altitude, pressure, and oxygen.

mm. HG.	Elevation.	O_2.	mm. HG.	Elevation.	O_2.
	Feet.	*Per cent.*		*Feet.*	*Per cent.*
760	0	20.96	412	16,000	11.39
732	1,000	20.15	397	17,000	10.97
704	2,000	19.38	382	18,000	10.56
677	3,000	18.64	368	19,000	10.16
651	4,000	17.93	354	20,000	9.78
626	5,000	17.25	341	21,000	9.41
602	6,000	16.60	328	22,000	9.05
579	7,000	15.97	315	23,000	8.70
557	8,000	15.37	303	24,000	8.35
536	9,000	14.80	290	25,000	8.01
516	10,000	14.25	278	26,000	7.68
497	11,000	13.73	266	27,000	7.35
478	12,000	13.23	254	28,000	7.03
461	13,000	12.75	242	29,000	6.71
444	14,000	12.28	230	30,000	6.40
428	15,000	11.83			

In order that the reasoning which led to the development of the rebreathing apparatus and the study of man under rebreathing may be understood, it will be necessary to insert here a brief statement concerning our knowledge of the effects of high altitudes. It has been known for a long time that man living at extremely high altitudes may develop what is popularly known as "mountain sickness," during which he exhibits certain definite symptoms. After a shorter or longer period of sojourn at the high altitude, these symptoms pass away and acclimatization takes place. During the last 40 years, but more particularly the last 18 years, physiologists have been carefully investigating "mountain sickness" and the adaptive changes that occur in the body of man and animals living at great altitudes. There has come from this study almost complete agreement of the investigators. There is, in fact, no room now for doubt that the essential cause of all the symptoms of altitude sickness and the adaptive changes within the body is the lack of oxygen, which is the result of the rarefaction of the air that occurs as altitude increases. The fact that there is oxygen want at high altitudes suggested the fact that any mechanism that would permit the breathing of a reduced amount of oxygen could be used to test the ability of men to withstand the effects of low oxygen. The rebreathing apparatus was designed not only to expose man to low oxygen but to a constantly decreasing amount of oxygen. A description of the apparatus and the method of use will be found elsewhere in this report.

In order that oxygen percentages may be translated into altitudes, the relation of altitude and oxygen, as well as altitude and pressure,

are shown in chart 1. On referring to the 12 per cent oxygen line, it will be observed that when the subject of experimentation is breathing 12 per cent oxygen, he is physiologically at an altitude of 14,400 feet, and when breathing 10 per cent oxygen the equivalent altitude is 19,400 feet.

One purpose in the method of examining aviators by rebreathing is to reproduce the gradually decreasing oxygen tension that they will experience as they ascend in the air. A sudden disturbance of bodily functions usually is manifested by symptoms of illness. The disturbance brought about by changes of altitude and by low oxygen cause the so-called "altitude sickness." Individuals differ greatly in the power of resistance. Hence, we find that altitude sickness

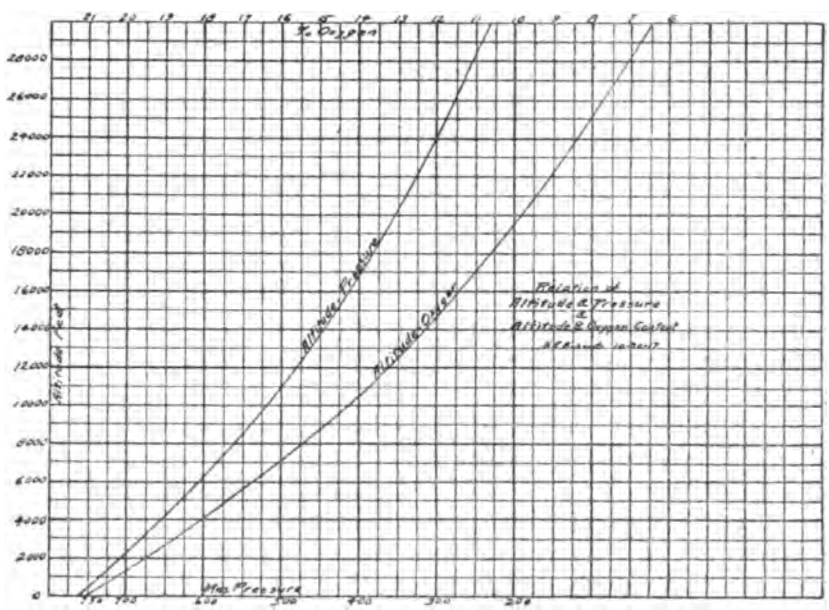


CHART 1.

attacks some at a lower, others at a higher altitude, but it is also certain that no one who proceeds beyond the elevation—that is, the critical line for him—escapes the malady. An elevation of 10,000 feet, or even less, may provoke it in some; others may escape up to 14,000 feet or even 17,000 feet; while only a few possessed of unusual resisting power can, without pronounced symptoms, venture upward to 18,000 feet. The flier himself may not be conscious of the symptoms when they first appear. The degree of illness will be determined by the length of time the subject is exposed to oxygen want. In the rebreathing experiments we produce artificially a mild attack of altitude sickness. The percentage of oxygen at which the symptoms appear will indicate the altitude at which similar

symptoms may be expected to occur, provided the length of time given to the rebreathing experiment has not been too short. Throughout rebreathing experiments attention has been directed to a stūdy of the pulse rate, the arterial blood pressure changes, the character and the volume of the breathing, and to the color changes in the skin and mucous membranes. It is well to recall here that in an attack of "mountain sickness" the pulse rate is always accelerated and the systolic and diastolic pressures are higher than in normal life. The patient may feel slightly giddy and there may be buzzing in the ears, dimmed sight, and fainting attacks. The face may be cyanosed and the eyes look dull and heavy. In some degree all of these conditions may occur as the subject undergoes the exposure to low oxygen tension during a rebreathing experiment. Many of the reactions here called "symptoms," which occur under low oxygen tension at high altitudes and during a rebreathing experiment, are simply compensatory changes by which nature endeavors to keep the tissues abundantly supplied with oxygen.

II.—THE PHYSIOLOGY OF REBREATHING AND AVIATION.

The physiological observations made on men and animals living at high altitudes or under reduced atmospheric pressures show clearly that a very marked process of adaptations occurs which renders the mechanism capable of meeting the call of the tissues for oxygen. The aviator must also be able to adapt himself physiologically to altitude changes. The aviator does not remain at high altitudes long enough to benefit from slow adaptive physiological changes, therefore his body must be capable of making rapid compensatory changes which will provide the oxygen needed by the tissues. He must be able to bear abrupt and great changes in atmospheric pressure. Without the occurrence of some one or more definite adaptive physiological responses to provide for his oxygen needs as he ascends, his life and aeroplane become more and more jeopardized as he continues to ascend.

That the body can and does respond to the demands for oxygen during rapid ascents has been proven by laboratory experiments and the experience of aviators and balloonists. The physiological responses that are definite, like those experienced by the mountaineer, are an increased ventilation of the lungs and a more rapid blood flow. In a few men a concentration of the blood may also occur.

It has been clearly established that the essential cause of the adaptive changes within the body when at high altitudes is the lack of oxygen, which is due to the rarefaction of the air that occurs as altitude increases. The fact that there is this oxygen want, suggested that any mechanism that would permit the breathing of a reduced amount of oxygen could be used to test the ability of men to with-

stand high altitudes. The rebreathing apparatus has been perfected for such tests. During the tests the subject breathes the air in the tank. He sits with a clip placed on the nose and with a comfortably adjusted mouthpiece in the mouth, which is suitably connected by means of inch tubing with light automatic valves. He inhales the air through the respiratory valve direct from the tank and exhales through the expiratory valve into a cartridge containing an absorbent for carbon dioxide. The exhaled air is thus freed from carbon dioxide as it is returned to the tank. A spirometer compensates for changes in volume and writes a record of the respiration upon the revolving drum of a kymograph. By this arrangement the subject continues to rebreathe the air in the tank from which he gradually absorbs oxygen. As the percentage of oxygen decreases, the subject, in effect physiologically, is slowly ascending to higher altitudes. The volume of air rebreathing is sufficient to require between 25 and 30 minutes to lower the amount of oxygen to 8 or 7 per cent, which is equivalent to altitudes of 25,000 to 28,000 feet.

A COMPARISON OF THE REBREATHING TEST AND THE DILUTION TEST.

Comparisons to date of the rebreathing and dilution tests upon the same individuals show a marked similarity in the reactions which occur and demonstrate conclusively that the adaptive changes occurring in both cases are due to low oxygen.

The dilution apparatus[1] used in our laboratory is an arrangement whereby it is possible to let pure atmospheric air or a mixture of atmospheric air and nitrogen pass into a breathing chamber and accordingly, at will, change the relative proportions between atmospheric air and nitrogen. This permits of changing the partial pressure of oxygen at any desired rate, thus producing the same effect as if the partial pressure of oxygen were reduced by mounting in the air.

The rebreathing machine is an apparatus whereby the subject rebreathes a specified amount of air from a tank, thereby causing a gradual and progressive decrease of the oxygen. The CO_2 of the expired air is removed by an absorbent and therefore is not a factor in the test.

Both tests are essentially low oxygen tests, as the nitrogen and CO_2 play no part in producing any of the adaptive changes.

The similarity and parallelism of the reactions in both tests upon the same individuals are marked.

A comparison of many charts showed the average point of acceleration of the pulse to be the same in both the Dilution Test and the Rebreathing Test. Also the limits of compensation for the systolic and diastolic were the same in both. A fall in the systolic at a cer-

[1] See Reports of the Air Medical Investigation Committee, No. 2, England.

tain percentage of oxygen in the Rebreathing Test was almost invariably accompanied by a fall in the systolic at the same percentage of oxygen in the Dilution Test. The same was true of the pulse rate and diastolic pressure.

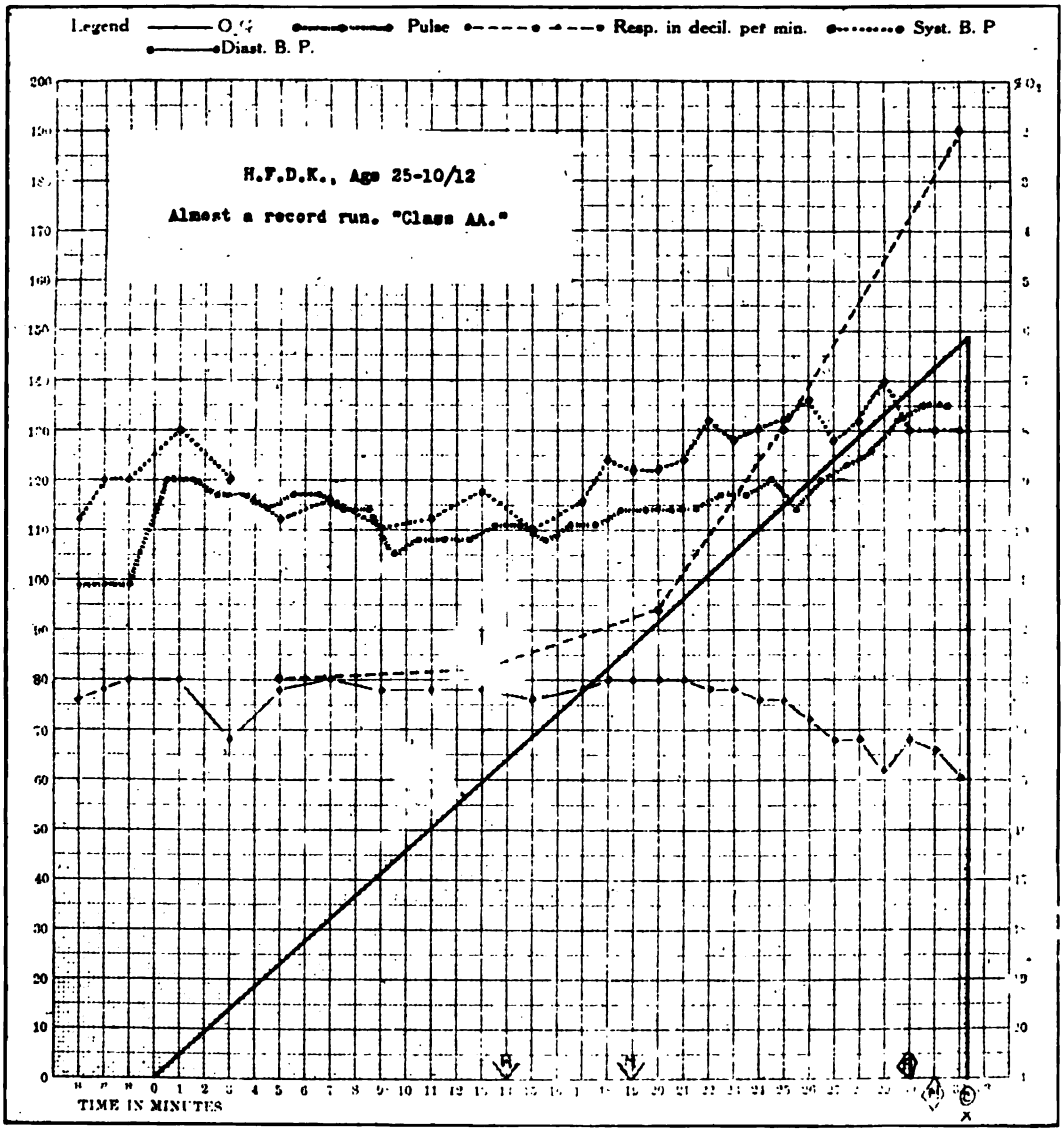
Throughout rebreathing experiments physiological, psychological, and other observations are made on the subject of the test. By the physiologist, the rate and per minute volume of respiration, pulse frequency, systolic and diastolic arterial pressures are studied for each candidate tested and have been found to give valuable evidence as to when he first responds to the reduction in oxygen and as to the efficacy of his compensatory reaction. Some men are sensitive to oxygen want and compensate in their breathing and circulation of the blood so that they endure as low as 6 per cent of oxygen. Others fail to compensate in one or both of these mechanisms or compensate inadequately and, therefore, can not endure so low an oxygen per cent. All gradations between failure to compensate and adequate compensation down to 6 per cent of oxygen have been found among the men examined under the low oxygen of the rebreathing tests. From the data obtained during the rebreathing test it becomes possible to determine approximately the maximum altitude to which the aviator may safely ascend.

THE BREATHING WHEN UNDER THE ACTION OF PROGRESSIVE DECREASE IN THE OXYGEN SUPPLY.

The character of the breathing undoubtedly has an important bearing on the ability of men to endure at high altitudes. The shallow breather is at a greater disadvantage than the man who breathes deeply when under the influence of low oxygen. In breathing a part of the fresh air remains in the nose, pharynx, larynx, trachea, and bronchial tubes and is emptied out again at the beginning of the next expiration in an almost unchanged condition, without having actually mingled with the air in the alveoli of the lungs. In shallow breathing, therefore, only a comparatively small amount of the fresh air gets past this so-called dead space to mingle with the air in contact with the blood vessels of the lungs. The deeper the breathing the greater will be the amount of fresh air that reaches the aveoli of the lungs and hence the greater will be the supply of oxygen for the body tissues.

The men examined have shown rates of breathing when sitting that ranged between 14 and 25 breaths per minute. Between 40 and 50 per cent breathed at the rate of 18 and 19 breaths per minute. The per minute volume of breathing ranged between 7 and 12.5 liters, with the majority between 8.5 and 9 liters. The average tidal volume of air breathed was 500 cubic centimeters for the group, while the extremes were 360 and 630 cubic centimeters, respectively.

DREYER LOW OXYGEN APPARATUS.


Legend O.G. Pulse Resp. in decil. per min. Syst. B. P Diast. B. P.
H.F.D.K., Age 25-10/12
Almost a record run. "Class AA."
TIME IN MINUTES

The smaller volumes of tidal air were found among subjects who breathed most frequently. Thus one man who breathed 24 times per minute had a tidal air volume of 375 cubic centimeters, while another whose rate was 14 per minute had a tidal air volume of 620 cubic centimeters. A slow, deep breathing will, as a rule, introduce more fresh air into the alveoli of the lungs than the shallow, rapid type of breathing.

As the percentage of oxygen gradually decreases during a rebreathing test there occurs a marked respiratory response to the lessening oxygen tension which increases the amount of air breathed per minute. This increase in the lung ventilation in a few men begins with the first decrease in the oxygen percentage of the air breathed and is a gradual proportional increase in inverse ratio with the reduction in oxygen. Over 50 per cent of the men examined gave the first respiratory response between 16 and 14 per cent of oxygen. Twenty-five per cent responded first at a lower oxygen tension, while a small number of men gave no respiratory response to the decrease in available oxygen. The increase in lung ventilation is for the higher percentage of oxygen only slight, but usually becomes more pronounced when the available oxygen has been decreased to between 12.5 and 9 per cent. (See charts 1–6.)

The rate of breathing for many men remain unchanged throughout the rebreathing test. The majority, however, show an increase of from two to four breaths per minute at between 8 and 6 per cent of oxygen. A few of the men examined, shown by other tests to be somewhat physically stale, increased the frequency of breathing enormously. Thus one subject, with a frequency of 22 when sitting quietly breathing atmospheric air, breathed 43 times per minute at 8.5 per cent of oxygen.

The amount per minute volume increase in the breathing during a rebreathing test differs with individuals. The majority of men examined show at per centages of oxygen between 8 and 6 per cent an increase of 5.5 liters over the volume breathed at the beginning of the experiment. This increase gives for the average man a total volume of breathing per minute of approximately 14 liters at oxygen tensions corresponding to an altitude of 25,000 feet. The total per minute volume of air breathed has, in exceptional cases, been as great as 26 and 37 liters of air at oxygen tensions corresponding to from 25,000 to 28,000 feet.

It is the depth of breathing which ordinarily is increased by low oxygen. The vast majority of subjects show an increase in depth of breathing of from 20 to 128 per cent when under 8.5 to 6 per cent oxygen. The volume of each breath in these men if found to range between 600 and 1,260 cubic centimeters, while for the same subjects when sitting quietly breathing atmospheric air the tidal volume is found to range between 360 and 630 cubic centimeters.

A good respiratory reaction to the gradual decrease in the oxygen of a rebreathing test will be manifest in a slight increase in the depth of breathing which begins at 16 or 15 per cent oxygen and continues to progressively increase slightly and gradually until 12.5 to 9 per cent of oxygen. From these percentages down to 8.5 and 6 per cent of oxygen the total per minute volume of breathing increases much more rapidly and the frequency of breathing may also then increase to from two to five breaths per minute. A total per minute increase of at least 5.5 liters should occur at the lower percentages of oxygen. The increase in the depth of breathing which occurs under low oxygen more effectively ventilates the alveoli of the lungs and, therefore, raises the alveolar oxygen tension above that which would be present if the breathing remained unchanged. Such an increase in alveolar oxygen permits the blood to be more thoroughly saturated with oxygen, and consequently the subject can endure a lower oxygen, which is equivalent to a higher altitude.

Some men have repeatedly been under observation, and most of those reacted very much the same each time when subjected to low oxygen. Thus one man who endured low oxygen unusually well in a series of seven tests averaged an increase of 6.5 liters in his breathing when breathing 7 per cent of oxygen. Another subject, who invariably suffered when under the influence of low oxygen, in a series of five tests during a period of eight days had an average increase of only 3.3 liters in lung ventilation.

When the per minute volume of breathing fails to increase as the amount of oxygen inhaled decreases, or when it increases only slightly—1 or 2 liters—the lung ventilation is sufficient and the subject will be found unable to tolerate as low a tension of oxygen as the man whose breathing gradually deepens as the available oxygen decreases. Only a few men have failed to show a respiratory response to low oxygen, and none of these have tolerated well such low oxygen as 10 to 9 per cent. Men whose respiratory center is insensitive to oxygen want either fail to show an increase in the breathing or are slow in doing so, and in either case there would be poor toleration of high altitudes.

An occasional subject has been examined whose breathing responded well at first, but later, when the percentage of oxygen was low, suddenly began to breathe less. When this happened fainting or unconsciousness quickly followed. One subject in three tests separated by intervals of several days suddenly showed a decrease in his breathing when at 10 per cent of oxygen. He fainted the first time and was only saved from doing so the others by being returned at once to atmospheric air.

THE CIRCULATION WHEN UNDER A DECREASING OXYGEN SUPPLY.

The rate of flow and the amount of oxygen passing from the blood to the tissues depends on the difference between the pressure of oxygen

in the blood and in the tissue. The higher the oxygen pressure in the blood the greater will be the amount of oxygen passing from the blood of the capillaries into the tissues. In active tissues the oxygen tension is always low. It is usually supposed that there is no oxygen pressure at all inside the cells. The dissociation of oxygen from the hemoglobin occurs with great rapidity and is greatest where the differences in pressure are greatest. It follows, therefore, that when the blood flows more rapidly through the capillaries of a tissue more oxygen will be made available than if it flows slowly. At high altitudes, or under low oxygen, the blood is, at first at least, less saturated with oxygen than at low altitudes. Therefore, if the blood contains less oxygen an increase in the rate of blood flow through the capillaries would be a means of providing the tissues with the oxygen demanded for their activity. An increased rate of blood flow has been demonstrated in men living at high altitudes and is undoubtedly one of the first of the adaptive or compensatory changes observed in the rapid ascents made by the aviator.

Circulatory observations made on Pike's Peak (14,110 feet) indicated that the increase in the rate of blood flow was the result of a greater frequency of heart beat and a dilatation of the arterioles.

A study of the pulse rate during exposure to low oxygen should, therefore, give a definite indication of the sensitiveness of the organism to low oxygen. We have found the pulse rate to be a trustworthy indicator of oxygen want provided care is taken at the beginning of a low oxygen or rebreathing experiment to have the subject calm and quiet. Excitement or anxiety may give a higher initial pulse rate, which will obscure the beginning of the oxygen want response.

Throughout the rebreathing test the candidate's pulse is counted for a period of 20 seconds each minute. The systolic and diastolic blood pressures are determined every other minute during the first part of the test and every minute after the oxygen has been reduced to approximately 11 per cent. The rate of heart beat has been found to accelerate in a few men at 17.5 per cent oxygen (5,000 feet). In one group of 70 men the accelerations began as follows:

1 per cent began to react between 7,000 and 8,000 feet	16. 0–15. 5 per cent oxygen.
12 per cent began to react between 8,000 and 9,000 feet	15. 5–14. 9 per cent oxygen.
20 per cent began to react between 9,000 and 10,000 feet	14. 9–14. 2 per cent oxygen.
14 per cent began to react between 10,000 and 11,000 feet	14. 2–13. 7 per cent oxygen.
23 per cent began to react between 11,000 and 12,000 feet	13. 7–13. 2 per cent oxygen.
20 per cent began to react between 12,000 and 13,000 feet	13. 2–12. 7 per cent oxygen.
6 per cent began to react between 13,000 and 14,000 feet	12. 7–12. 2 per cent oxygen.

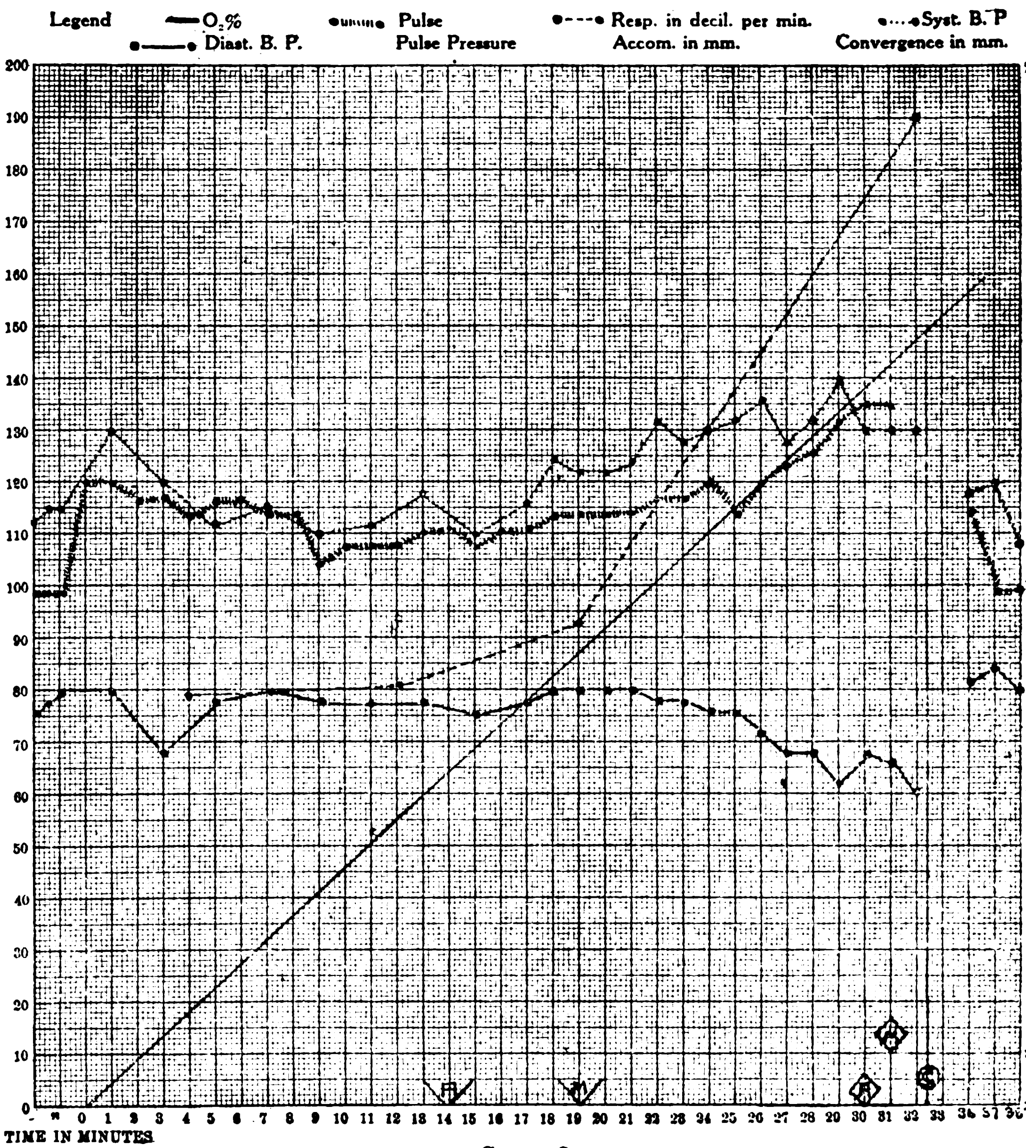


CHART 2.

No. 155.—H. F. D. K. CADET. Age 25 years, 10 months.

This is almost a record run for low percentage reached, and preservation of efficiency practically unimpaired until the very last. Pulse rather high from the start, as is often the case in subjects who compensate particularly well, and both pulse and blood pressure show some psychic influence at the start. During the course of the test there is a typical moderate rise in pulse and systolic pressure and a gradual tendency downward of the diastolic pressure. No suggestion of circulatory exhaustion. Rated AA, a particularly good subject.

The increase in heart-beat frequency is at first slight, only from one to three beats, but as the oxygen percentage decreases a greater increase in rate is likely to occur with each decrement in oxygen. A very marked acceleration usually occurs when the oxygen has fallen to between 13 and 9 per cent. In some men after the beginning of the more rapid increase in acceleration a steady increase in rate occurs down to even 6.5 or 6 per cent oxygen, while in others after a period of rapid acceleration the amount of acceleration becomes less with each decrease of 1 per cent in oxygen. The last condition suggests that the power to compensate has about reached its maximum. Some men at first react with a good acceleration in rate but soon reach a rate beyond which there will be no further response, even though the oxygen percentage continues to be lowered. In such cases after holding at a fixed rate for a while the heart suddenly begins to slow, a sure indication that the limit of endurance has been reached.

A total increase of from 15 to 40 beats in the heart rate during a rebreathing test in which the oxygen is lowered to between 7.5 and 6.5 per cent constitutes a good reaction to oxygen want. A failure to respond by an acceleration in heart beat to lowered oxygen either means inability to react to the low oxygen of high altitudes and early failure or it may mean that sufficient compensation is secured by increased breathing or blood concentration, or both. Our experience indicates that the failure to respond is associated with poor toleration of low oxygen. An acceleration in heart rate of more than 40 beats—50 to 70 have been observed—throws too great a burden on the circulatory mechanism and occurs only in men who do not tolerate well low percentages of oxygen. In such men other compensatory reactions may fail to occur. So far as the response in pulse rate to decreasing oxygen is concerned it therefore becomes possible to rate the reactions as poor, good, and excessive. A poor or an excessive heart response should disqualify the candidate for very high altitudes; he should only ascend to moderate heights.

A delay in the first appearance of acceleration of the heart rate may be due to an insensitive cardiac brain center and an early response may indicate a mechanism very sensitive and responsive to any decrease in available oxygen. It should be borne in mind, however, that while ordinarily there is an early acceleration in the heart rate, a delay may be due to the efficiency of other methods of compensating to the stimulus of oxygen want.

The determination of systolic and diastolic arterial blood pressures show whether the vasomotor mechanism responds to the stimulus of oxygen want in an adequate manner for maintaining the increase in the rate of blood flow and at the same time whether the heart is compelled to work against an increased resistance. They further give an index, the pulse pressure, of the volume of ventricular output.

COLOR CHANGES DURING REBREATHING.

The skin-color changes also give a satisfactory means of judging the reaction of the subject to low oxygen. The normal condition is a gradual development of cyanosis. In a healthy reaction this is delayed in its onset; in a poor case it appears early and becomes much more pronounced as rebreathing continues. Some men do not show a well-defined cyanosis but become pale and deathlike in color. This is not a good reaction and may be found associated with other symptoms—heart and circulatory—which disqualify for high altitudes.

THE DURATION OF THE REBREATHING TEST.

The length of time taken to reach a low oxygen in the rebreathing test will profoundly alter the ability to endure extremely low percentages. If the oxygen is lowered rapidly the candidate compensates to a lower percentage than is possible where the rate of decrease in the oxygen is slower. Three rebreathing experiments made on the same subject illustrate the condition. The volume of air was so small for the first test that in 23½ minutes the oxygen was lowered to 6.3 per cent, at which the subject's power of compensation failed. The next day rebreathing a larger volume of air for 38 minutes he compensated to 7 per cent only. On the following day in a test of 85 minutes' duration, compensation failed at 8.7 per cent of oxygen. Individual differences will be found; in some men time has a more profound influence than in others. Thus another subject compensated in a test of 36 minutes down to 7.5 per cent and in one of 90 minutes to 8 per cent of oxygen. Therefore, when testing ability to endure low oxygen, some allowance must be made for the time taken to reach a given percentage. If each of two men tolerate down to 7 per cent oxygen but one is carried down in 20 and the other in 40 minutes, the one who endures for 40 minutes will have the better power of compensation.

Control tests have been conducted in the pneumatic or low-pressure chamber to determine the reliability of the rebreathing test. A subject was first under observation in a rebreathing test and again on the following day taken into the low-pressure chamber for similar observations, while the pressure was lowered at the same rate that the oxygen had been absorbed in the rebreathing test. The breathing, pulse rate, and blood pressures reacted about the same in each experiment. In order that a comparison might be made of the breathing under the two conditions, the alveolar air was analyzed from time to time during each kind of test. A fall in the alveolar carbon dioxide and oxygen pressure occurred in both experiences. The average amount of fall for eight men at the per cent of oxygen or pressure corresponding to 20,000 feet was for carbon dioxide during rebreath-

ing 8.5 millimeters and low pressure 9.3 millimeters; for the oxygen in rebreathing 66.2 millimeters and low pressure 68.8 millimeters. These figures show that the increase in the breathing and lung ventilation was about the same under the two different low-oxygen experiences. The pulse rate also was found to begin to accelerate at about the same time in each kind of test and to accelerate in equal degree. These and other physiological observations made on men undergoing the rebreathing test or under decreasing atmospheric pressure prove that the same compensations are used by the body in each, and these we know are the adjustments made to the influence of oxygen want.

In the optimum type of response to the low oxygen of the rebreathing test the systolic pressure remains unchanged; that is, it holds on a level, until the oxygen has been lowered to between 14 and 9 per cent after which, as the oxygen is further lowered, it gradually rises, or there may occasionally occur a gradual rise in the systolic pressure beginning with the first increase in heart rate (see chart 3). This rise in pressure is ordinarily to from 15 to 20 mm. Hg. Other subjects who appear to have tolerated low oxygen well, even to as low as 6.5 per cent of oxygen, have had a systolic pressure which held at the normal (see chart 2).

A rise in the systolic pressure of more than 30 mm. Hg.—40 to 60 mm. have been observed—is very likely due to a vasomotor failure to respond with a dilatation of the arterioles. Such conditions will lead to overwork by the heart and may result in early circulatory failure.

There are other conditions of systolic pressure that are occasionally found in men undergoing the rebreathing test. A small percentage of subjects examined had a fall in the systolic pressure which began about the time the pulse rate started to accelerate and continued to decline throughout the test. Such men have not tolerated the extremely low percentages of oxygen that men of the optimum type of response have endured.

A large percentage of subjects have shown a sharp and sudden fall in the systolic pressure at low percentages of oxygen. This fall if allowed to continue will lead to fainting. The subject recovers his normal pressure at once if he is returned to atmospheric air.

The best condition in the response of the diastolic pressure to a decreasing oxygen supply consists in an unchanged or slightly increased pressure throughout the test. Many men show a gradual well-controlled fall in the diastolic pressure (see charts 5 and 6) during the terminal period when the systolic pressure is rising. Such a fall in the diastolic pressure if it occurs slowly and is not great constitutes a fairly good reaction to extreme oxygen want and can be explained as a vasomotor dilatation which occurs in order to protect the heart against the rising systolic pressure. In the optimum type of response to low oxygen the terminal fall in the diastolic pressure may not

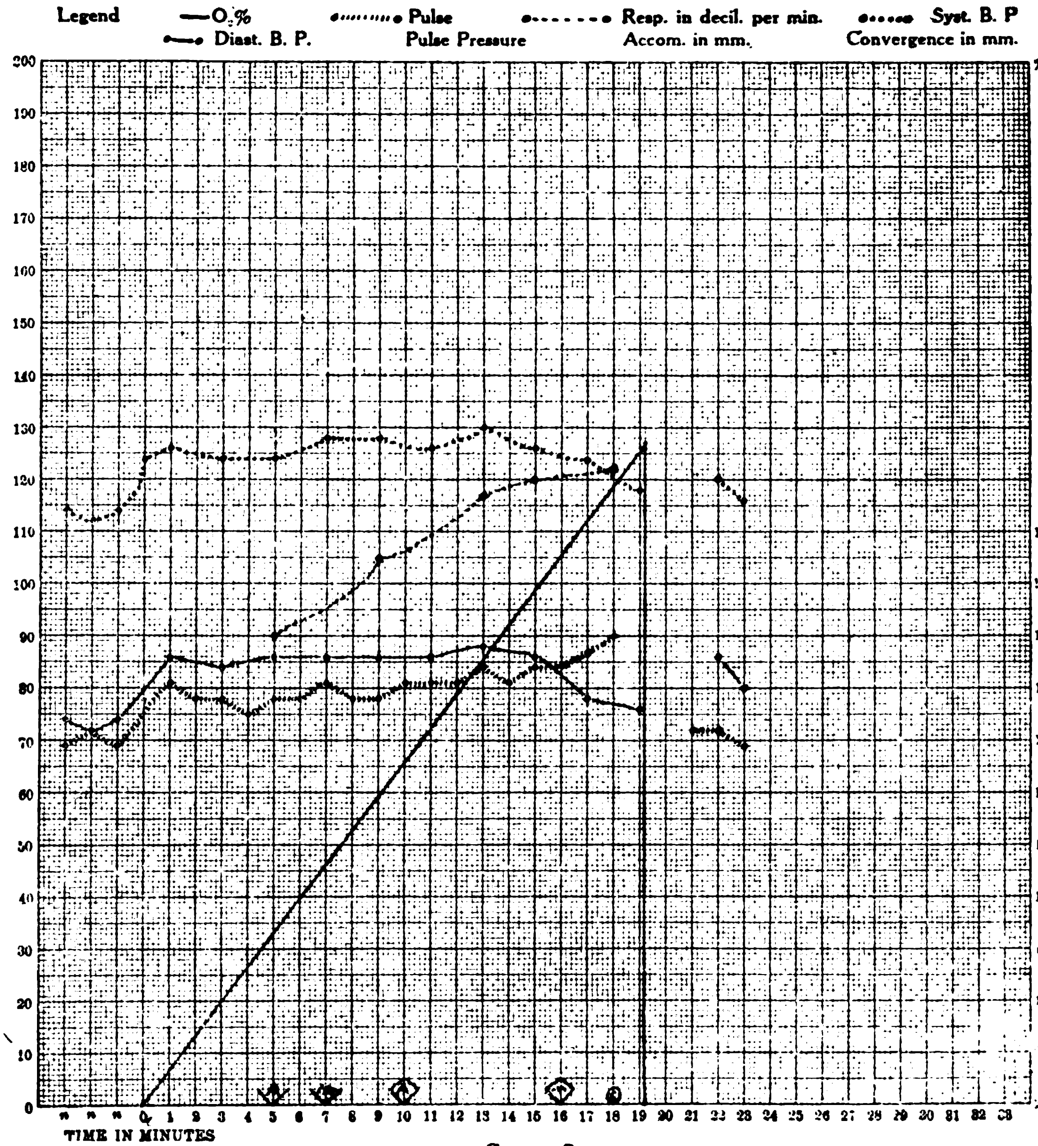


CHART 3.

No. 50.—E. O. T., 2d Lieut. PILOT. Age 31 years 8 months.

In good health, but "out of training" and 20 pounds overweight.

This chart shows almost total failure to compensate. There is very little change in pulse or blood pressure, and the respiratory reaction is deficient. For this reason there is early appearance of inefficiency as shown by the psychological characters, and he is "completely inefficient" above 9 per cent. Since there is no circulatory reaction, there is no evidence of strain. Class C. "Becomes inefficient at a relatively low altitude."

occur, and if present is never very pronounced and does not occur before the oxygen is reduced to 9.5 per cent or less.

About 66 per cent of all men examined have had a fall in the diastolic pressure. At least half of these have been sudden and great. The rapid fall is always associated with fainting, and usually precedes a systolic fall. If the two occur together, in the order just indicated, the experiment must be terminated at once if fainting is to be prevented. The pronounced and sudden fall in diastolic pressure may occur at a high oxygen percentage. It has been found to occur as early as 14 and 13 per cent of oxygen (10,400 and 12,200 feet). Such sudden falls in the diastolic pressure appear to be due to an overcoming of the vasomotor center by oxygen shortage. A decided fall in the diastolic pressure even if more or less definitely controlled is an indication that the subject will not tolerate well the altitude corresponding to the oxygen percentage at which it appears.

Three types of circulatory reaction to oxygen want have been observed. The first, the optimum, in which the pulse rate accelerates moderately as the oxygen decreases, the systolic pressure is unchanged or shows a terminal rise of not more than 20 to 30 mm. Hg., and the diastolic pressure remains unchanged or rises slightly (see chart 2). The second, the controlled diastolic fall, in which the pulse rate accelerated moderately and the systolic pressure rises as the diastolic pressure gradually falls (see charts 3 and 6). The third, the fainting type (see charts 1 and 4), in which after a period of fair, good, or excessive response in the rate of heart beats to low oxygen the diastolic pressure suddenly falls and soon thereafter the systolic pressure falls and the pulse rate slows. The optimum type may tolerate as low an oxygen as 6 per cent and may lose consciousness without fainting. He recovers quickly when restored to air, while the heart rate and blood pressures are soon back to their normals. The fainting type rarely endures as low an oxygen and if allowed to run his course faints completely, and as he revives he requires a considerable time, sometimes an hour or two, to regain his normal pulse rate and blood pressures. There are, of course, gradations between the types here described.

The pulse pressure during a rebreathing test remains fairly constant in most men until the oxygen has fallen to between 12 and 9 per cent (14,500—22,000 feet), after which it increases in amount during the further reduction in oxygen. The rise in pulse pressure occurs when the systolic pressure is rising and the diastolic either remaining constant or slowly falling. This is also the period when the heart beat is accelerating most rapidly. The amplitude of the heart output, it is claimed, is shown by the pulse pressure; if the

pulse pressure be multiplied by the pulse rate and the product be taken as a relative measure of the volume of the blood stream and increase in the circulation rate will be indicated, beginning between 16 and 14 per cent of oxygen and progressively increasing as the oxygen further decreases. The period of most rapid flow of blood would, therefore, be that when the pulse pressure is also increasing, that is, from between 12 and 9 per cent of oxygen to the end of the test. Therefore a marked increase in the rate of the circulation of the blood during exposure to a low and decreasing oxygen is indicated. This increase in blood flow is, as shown earlier, an important and necessary compensatory reaction to low oxygen.

Incidentally a few venous blood pressure determinations made during exposure to a decreasing oxygen supply have shown a drop in venous pressure, which becomes very pronounced when the oxygen is 10 per cent or less. The following are typical examples:

1. Normal venous blood pressure was 10.8 centimeters of blood. After 25 minutes, during which time the oxygen was gradually decreased to 8 per cent, it had fallen to 3.5 centimeters of blood. Returned to normal within five minutes after being returned to air.

2. Normal venous pressures 9 centimeters; 20 minutes later at 10 per cent oxygen, 3.5 centimeters. Return to normal after experiment required 15 minutes.

3. Normal, 6.6 centimeters; fell to 5 centimeters in 30 minutes when the oxygen had reached 7.5 per cent.

This fall in venous pressure calls to mind a similar fall reported by Schneider and Sisco in men on Pike's Peak, and it indicates that the reactions observed in the rebreathing tests are the result of the same cause—low oxygen.

VENOUS PRESSURE.

For the determination we used a tilting table, which made it easy to study the subject in the horizontal position. The subjects of our studies were officers and enlisted men of the laboratory, presumably normal men.

Venous pressure was determined by noting the height to which the arm could be lifted before some prominent bit of vein in or near the hollow of the elbow collapsed, and comparing this with the height of the point of reference between these two levels, read in centimeters, gives the venous pressure directly in centimeters of blood.

The point of reference was taken as 5 centimeters below the level of the nipple, and this level was carried away from the breast by means of a simple spirit level. Measurements were read on a centimeter rule suspended from the ceiling.

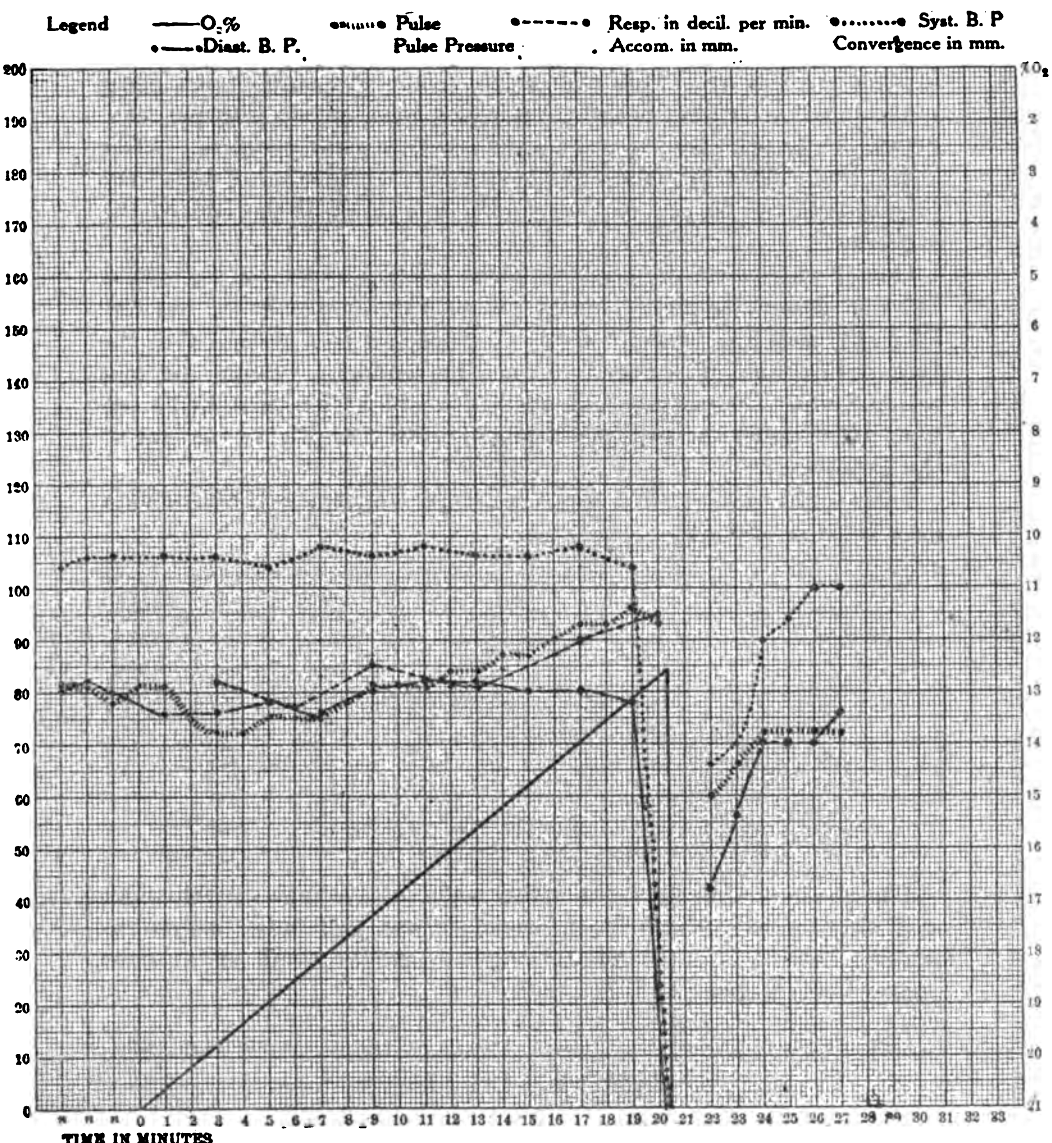


CHART 4.

No. 144.—L. R. S. CADET. Age 20 years, 2 months.

Is decidedly "stale," hates to go up in the air at all. Feels tired and depressed, and is discontented in the service at present. Certain complications at home are on his mind a good deal.

This chart is typical of a man in poor physical and mental condition. He fainted rather suddenly at about 18 per cent. Previous to this he had shown little compensatory response; blood pressure too low from the start, pulse rising slightly and respiration hardly at all affected. This man might be expected to faint at any time during a flight, irrespective of elevation.

No rating given, but for the time being is unfit to fly at all. Withdrawn from flying and recommendation made for furlough.

The data on the venous pressure study, though meager as yet, are sufficient to show that with an increase of altitude there is a decrease in venous pressure. This change in venous pressure shows great individual variations, ranging from 4.1 per cent to 104 per cent drops. Only one case showed a final rise in venous pressure. After a drop from 8.3 centimeters of blood to 5.3 centimeters of blood the pressure started to rise and continued to rise until the end of the experiment.

Out of nine cases, the one mentioned above was the only one that did not show a lowered venous pressure under decreased oxygen. In many cases the pressure showed a tendency to decrease with the first indications of lowered oxygen percentage. Others did not respond until the oxygen had reached about 13 per cent to 14 per cent, after which the pressure dropped quite abruptly to the end of the experiment.

From eight cases studied with the Dreyer apparatus, the following data were compiled:

	Normal V. P.	Fall in V. P.	Per cent fall.	O_2.
	Cm. blood.	*Cm. blood.*	*Per cent.*	*Per cent.*
1	8.75	9.05	104.0	10.2
2	6.45	2.40	37.2	7.5
3	4.48	.98	21.8	8.5
4	9.70	6.25	64.5	6.6
5	2.40	1.10	45.8	10.0
6	4.03	2.58	64.0	7.3
7	6.30	3.50	55.5	8.7
8	6.88	.28	4.1	8.63
Average	6.12	3.27	49.6	8.43

The above studies bear out rather well the findings of Schneider and Sisco in their Pike's Peak investigations, and indicate that the reactions observed in the rebreathing tests are the result of the same cause—low oxygen.

THE RELATION OF VITAL CAPACITY, POWER TO HOLD THE BREATH AND ENDURANCE OF LOW OXYGEN.

The English suggest the rejection of all candidates with a vital capacity below 3,000 cc. and view with suspicion all below 3·400 cc. The candidate also should be able to hold the breath a minimum, in three times, of 45 seconds. They find that good pilots manage 60 seconds or more. If dizziness, blurred vision, etc., occur under 40 seconds, they reject the candidate, no matter what the vital capacity may be. A further test often applied is to have the candidate hold the breath after the moderate exercise of stooping and touching the floor four times. After the exercise the candidate should be able to hold the breath 30 seconds. Good pilots hold at least 40 seconds, gen-

erally between 50 and 60 seconds. None of the men examined by us had a vital capacity less than 3,400 cc. Four who were unable to endure a low percentage of oxygen in the rebreathing experiments had vital capacities ranging between 4,400 and 5,000 cc. In view of our observations it appears that the vital capacity does not serve as an index for the approximation of the limits of endurance of low oxygen (see following table prepared from observation on 50 men).

Subject.	Vital capacity.	Holding of breath.		Lowest per cent of oxygen endured.	Danger percentage.
		Before exercise.	After exercise.		
		Seconds.	*Seconds.*	*Per cent.*	
An	4,200	40	24	6.8	Not reached.
Br.	5,000	75	50	8.4	10.
Be.	4,600	80	58	9.2	9.2.
Cl	3,800	47	38	6.6	8.3.
Fin.	4,500	107	34	9.8	11.3.
Fer.	4,350	72	57	7.2	11.3.
Gln.	4,400	60	54	6.8	Not reached.
Kr.	3,800	76	40	8.8	10.
Par.	5,200	56	57	6.3	6.3.
Roc	4,500	62	30	7.3	10.3.
Sch.	4,750	75	74	6.3	7.7.
Sny	4,700	60	24	6.7	8.
Tr.	3,650	62	32	8.2	8.2.
W	4,200	29	20	7.3	Not reached.

An., with a vital capacity less than that of Br., Be., and Fin., had not completely reached the limit of endurance at 6.8 per cent (28,400 feet), while Br. failed at 8.4 per cent (24,000 feet), Be. fainted at 9.2 per cent (21,800 feet), and Fin. at 9.8 (20,000 feet). Compare the last three with Cl., whose vital capacity was only 3,800 cc., and who endured low oxygen down to 6.6 per cent.

The length of time the breath was held did not give an indication of how low in oxygen the subject would go on the rebreathing apparatus. Fin. and Be., who fainted at 9.8 per cent (20,000 feet) and 9.2 per cent (21,800 feet), respectively, held the breath longer than the average. An., who managed only 40 seconds, withstood 6.8 per cent oxygen (28,400 feet), and W., who held only 29 seconds, endured low oxygen down to 7.5 per cent (26,000 feet).

VITAL CAPACITY AND INTESTINAL GASES AT HIGH ALTITUDES.

That vital capacity of the lungs decreases with lowering atmospheric pressure has long been established by investigations carried on in this country and abroad. The cause of the decreased vital capacity at high altitudes has not, however, been wholly determined. That oxygen want plays a part in this as well as in other physiologic low-pressure symptoms seems, from our investigations, to be practically certain. That oxygen want alone is not wholly responsible seems equally certain.

For our investigations we used a simple water spirometer with a capacity of about 7 liters. The work was done in the low-pressure chamber under conditions simulating those encountered at altitudes ranging between sea level and 22,000 feet.

First a series of observations was made in which the subjects were taken to 20,000 feet, without oxygen, to determine the amount of decrease in vital capacity. In 17 cases the average decrease was 0.48 liter (approximately 10 per cent), the maximum 1.08 liters (25 per cent), and the minimum 0.15 liter (3 per cent). A well-defined decrease does not occur below 10,000 feet; the majority of men seem to hold on well to 12,000 to 14,000 feet. In this connection it is interesting to note that three men who have lived most of their lives at altitudes above 5,000 feet retained their normal vital capacity to greater altitudes than did the men who had always lived at low altitudes. In one the first break came at 14,000 feet, the second held to 16,000 feet, and the third was still normal at 18,000 feet. On the other hand, several whose homes had been at less than 1,000 feet showed a decreased capacity at 10,000 feet.

A second series was run in which the subjects took oxygen throughout the experiment, and in this series there also occurred a decrease in vital capacity. In six cases, going from sea level to 20,000 feet, the average decrease in vital capacity was 0.20 liter, or 4.5 per cent below normal.

A number of men were taken to 20,000 feet without oxygen. At that altitude they were given oxygen and held a sufficient length of time for the oxygen to effect the system. The usual decrease to 20,000 without oxygen was observed. When oxygen was administered a definite and unmistakable return toward the normal was noted, but in no case did the readings at 20,000 feet equal the normal readings at sea level. In a study of six cases the following data were obtained:

Average V. C. at sea level	4.45
Average V. C. at 20,000 feet without O_2	3.94
Average V. C. at 20,000 feet after taking O_2	4.23

That the aviator may be distressed by an abdominal bloating due to expansion of gases in the intestine during an ascent has been suggested. The gases accumulated in the digestive organs expand as the external pressure falls so that at 18,000 feet—that is, half an atmosphere of pressure—the gases in the digestive organs will expand to double their volume. This may lead to an unpleasant pressure on the abdominal wall and diaphragm and this, it has been suggested, might cause difficulty in breathing by forcing up the diaphragm and thus decreasing the space of the thoracic cavity. When gas forms continually in the digestive organs in consequence of a diet rich in carbohydrate foods, such as sugars, green vegetables, and others that are easily fermented, the decrease in vital capacity might be expected

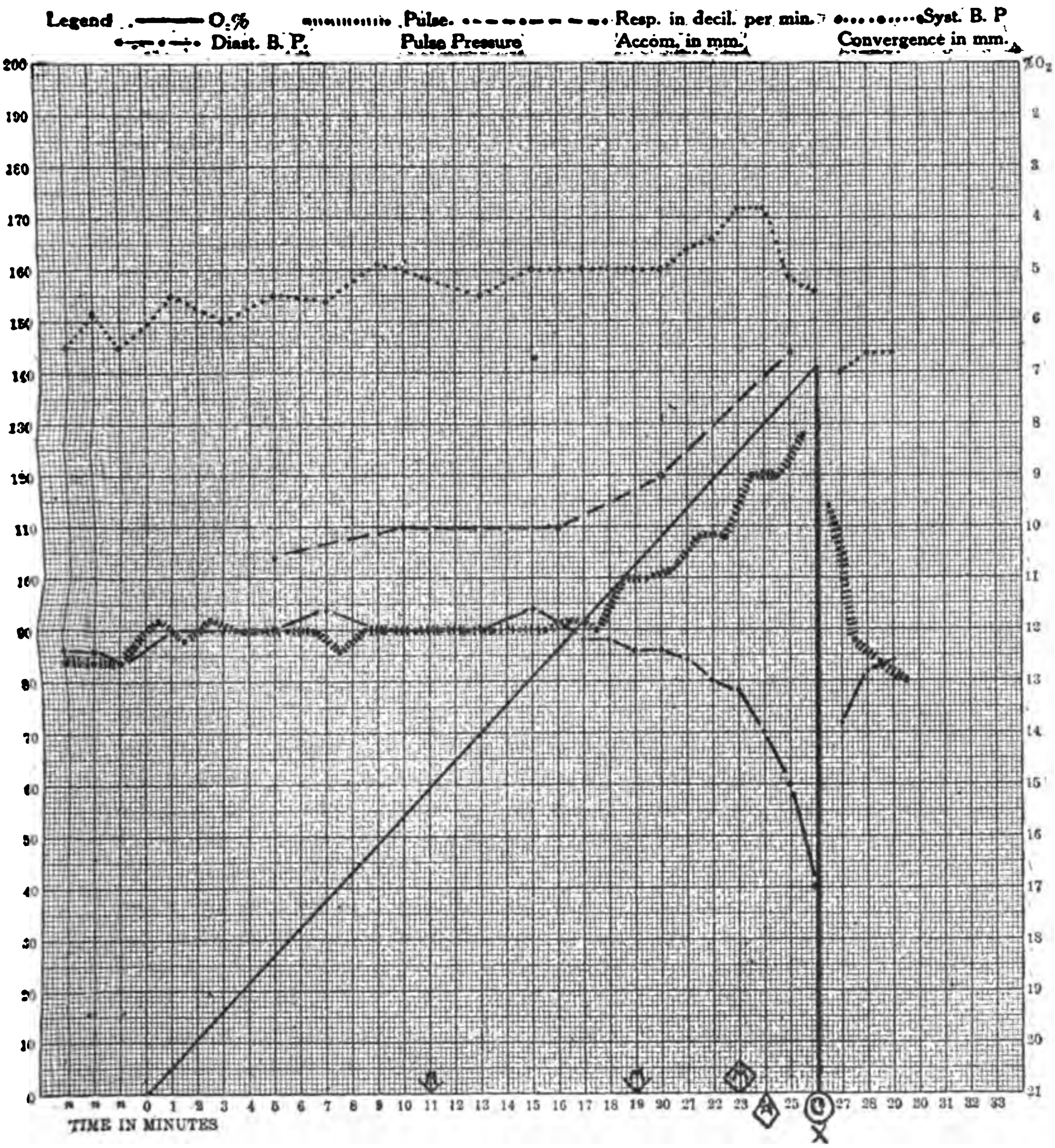


Chart 5.

No. 352.—R. P. E. CADET. Age 22 years, 7 months.

Preliminary blood pressures: Reclining, 134; standing, 142; after exercise, 160; two minutes later, 134.

During the test has a high and gradually increasing systolic pressure. Diastolic comes down rather steeply after 20 minutes (10 per cent), though never out of control. Pulse and respiration normal. Marked psychic effects soon after diastolic pressure begins to fall. High blood pressure, with signs of fatigue, but candidate in class C in spite of his reaching a fairly low percentage before the actual break.

to be greater than in the man in whom little or no fermentation is occurring. Careful study of this condition failed to establish any relation between abdominal bloating and the decrease in vital capacity during experiments in the low-pressure chamber. It was found that the abdominal measurements may vary greatly at any single pressure while the vital capacity remains constant. Belching or otherwise releasing the digestive gases reduced the abdominal measurements and materially relieved the distress of the subject without causing any noticeable change in the vital capacity.

The decrease in vital capacity of the lungs appears, therefore, to be largely due to the oxygen want of high altitudes and not to be caused by the pushing up of the diaphragm by the expanding gases of the intestines.

VASOMOTOR TONE AND ENDURANCE OF LOW OXYGEN.

Since physical fitness has been found to influence profoundly the ability of men to endure low oxygen it was thought that Crampton's "blood ptosis test" might be used to approximate the altitude the aviator could tolerate. The vasomotor mechanism is easily wearied and damaged by unhygienic influences. The fact that the vasomotor control of the splanchnic area in man experiences a change of adjustment when the body is moved from the horizontal to the upright-standing position has been used by Crampton to devise a percentage scale of vasomotor tone for rating. In vigorous subjects the heart rate does not increase on standing but in wearied subjects it increases as much as 44 beats per minute. In a perfectly strong subject the splanchnic vasotone will increase on standing and raise the systolic blood pressure about 10 millimeters of Hg. while in an individual weakened by dissipation, overwork, or lack of sleep the pressure will tend not to rise but to fall. To estimate the vasomotor tone the pulse rate and the systolic pressure are determined on a subject after reclining five minutes and again after he is required to stand. A subject sometimes may show weakness by a decrease in blood pressure and at other times by an increase in heart rate, and vice versa. It was determined that a decrease of one millimeter of mercury was equivalent to an increase in heart rate of approximately two beats.

A study of 130 aviators in which the vasomotor tone index was compared with the physiological compensatory reactions during exposure to the influence of the low oxygen of the rebreathing test has shown that Crampton's vasomotor tone index does not give a reliable indication of the subject's ability to withstand low oxygen tensions. When the candidates are arranged in the four groups of our scheme for classifying aviators the AA group has an average vasomotor tone of 88.75, the A's 68.25, the B's 57, and the C's 68.13. Collectively, therefore, the vasomotor tone index appears to furnish information

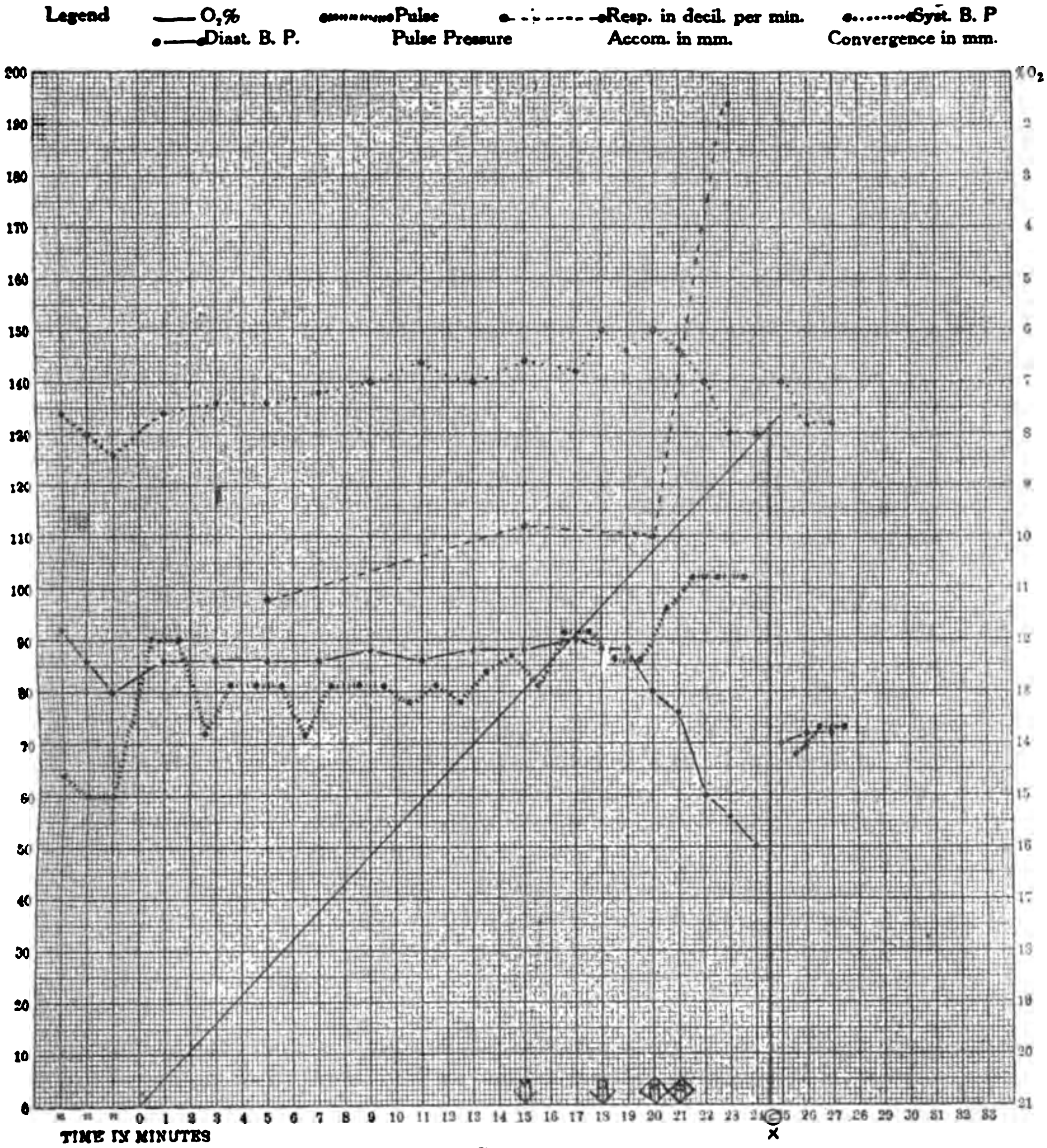


CHART 6.

No. 351.—W. S. Age 20 years 4 months.

Preliminary blood pressures: Reclining, 122; standing, 138; after exercise, 156, and two minutes later, 138.

During the test the pressure is a little high and trends upward. The diastolic pressure begins to fall rather rapidly after the nineteenth minute (10.5 per cent), but is never out of control. At the same time systolic pressure falls somewhat and the pulse fails to advance. This is the picture of circulatory fatigue, and if pushed much longer collapse would follow. Note that marked psychological effects (diamonds) appear just as the circulatory fatigue becomes manifest. Complete inefficiency at a rather high percentage (8 per cent). Class B.

that might be useful except for the C group. The number of men in class C is rather small, 5 in all, so that the chance for error is greater. An examination of the individual cases in the four groups shows clearly that the Crampton vasomotor tone index can not be depended upon as a test for ability to react to low oxygen. Thus among the A's are vasomotor tones as low as 30 and as high as 110, among the B's 15 and 105. With such a wide range of variation it becomes evident that the vasomotor tone index can not be substituted for the rebreathing test. Low vasomotor tone is no doubt present in physically stale men, but it also occurs in men temporarily fatigued.

THE PULSE RATE AND BLOOD PRESSURES AFTER PHYSICAL EXERTION.

It is generally assumed that in vigorous physically fit men the rate of heart beat does not accelerate as much during a given exercise as in men out of training and therefore physically "soft." Furthermore, in the physically fit the rate returns to normal quickly, while in the less strong a higher rate is maintained some time after exercising. After short periods of exertion the pulse rate usually goes subnormal, but after fatiguing and exhausting exercise returns to normal more slowly and only rarely passes into the subnormal stage. The amount of increase in the heart rate and the time required to return to normal may be used as a measure of physical fitness.

All aviators and candidates examined in the Medical Research Laboratories undergo the following test: The candidate stands at ease while his pulse rate is counted; when two successive counts are the same the rate is recorded, and the arterial blood pressures immediately taken. The candidate then places his right foot on a chair and raises himself five times to the erect position on the chair. This exercise requires about 15 seconds. Immediately thereafter the pulse rate is counted for 20 seconds, and next, as quickly as possible, the arterial pressures are determined. He then stands at ease for two minutes, after which the pulse rate and pressures are again taken.

An analysis of 170 cases taken at random has been made and comparisons made with the reaction of the candidate to the low oxygen of the rebreathing test. Also a comparison with the vasomotor tone has been made. The following changes in pulse rate were obtained immediately after the exercise: Decrease in 7.1 per cent, no change in 7.6 per cent, an increase of from 1 to 10 beats in 38.2 per cent, an increase of from 11 to 20 in 34.1 per cent, and 21 to 30 in 13 per cent. Just what increase in the rate of heart beat is excessive is yet to be determined. Maj. Flack and Capt. Bowdler conclude for the same exercise that an increased rate of over 25 and a return period of over 30 seconds are points calling for careful consideration. Only 6.5

per cent of our subjects had an increase of over 25 beats. On comparing the above data with the showing the men made in ability to compensate to the low oxygen of the rebreathing test, we find no definite relationship indicated between the amount of acceleration after exercise and endurance of low oxygen. Neither do we find a relationship between the exertion pulse rate acceleration and Crampton's vasomotor tone index.

We did not follow the return of the pulse rate to normal after exercise but noted the rate two minutes after. The rate at the end of the second minute was above normal in 33 per cent, normal in 16.8 per cent, and subnormal in 50.2 per cent of the men. None of the subjects had a rate of over 10 above normal at the end of two minutes. The number above normal is certainly excessive according to the standards of Flack and Bowdler. In this study no relationship could be established with the ability to compensate to low oxygen nor with the vasomotor tone.

The changes in the systolic pressure immediately after the exercise show nothing definite as to physical condition and as to ability to endure low oxygen. The systolic pressure two minutes after exercise, when compared with the pulse rate changes, show collectively interesting differences. The group with the pulse rate above normal had systolic pressures above normal in 22.8 per cent and below normal in 66 per cent of the men; those whose pulse rate had returned to normal showed 68 per cent above and 18 per cent below the normal systolic pressure; while in those in which the pulse rate was subnormal 82.1 per cent were above and only 7.1 per cent below their normal systolic pressure. It appears, therefore, that when the heart rate remains up after exercise the systolic pressure more frequently becomes subnormal. This observation has not been found to bear upon the ability of men to react to low oxygen. It does, however, indicate that the vasomotor tone index is a more reliable method of judging fatigue and possibly staleness than either a study of the pulse rate or systolic pressure alone.

Flack and Bowdler believe the ideal pulse rate for a flying officer has a small range between systolic and diastolic pressures (20–30) with a rest rate increased 20–25 by exercise and returning to the rest rate in 10–15 seconds. They further state that a pulse of 60 to 72 little raised by exercise (10 beats per minute) and returning to normal in 10 seconds is a good sign, generally associated with excellent physique and good stability of the nervous system. We have no reason to doubt their conclusion but believe the values given may be increased by a good margin and still retain the physical perfection desired. About 37 per cent of our subjects had when standing upright pulse rates above 85 and the pulse pressures of the great ma-

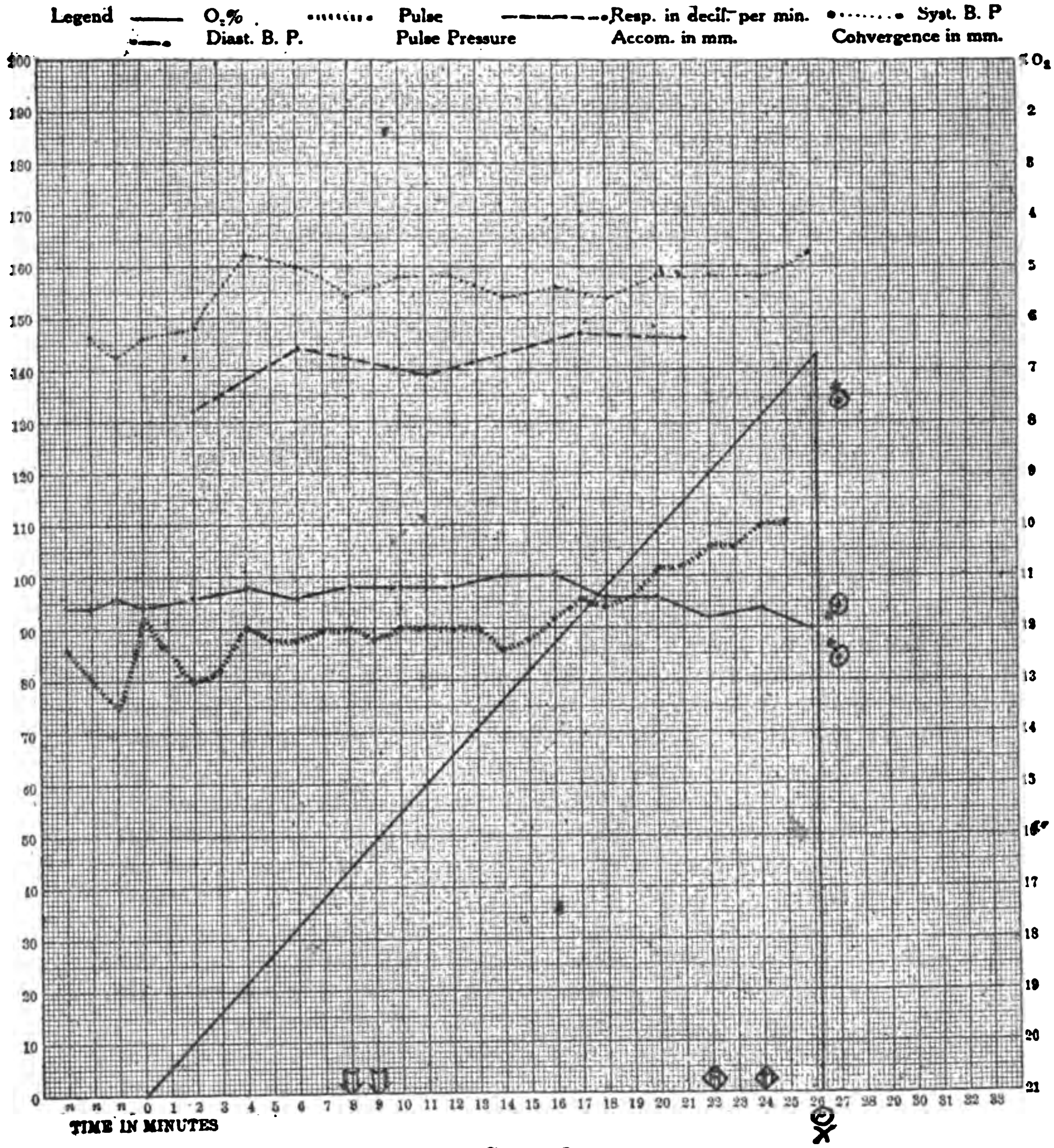


CHART 8.

No. 110.—R. S. CADET. Age 35 years 11 months.

This chart is of a type which is not uncommon among older subjects, and must be interpreted either as decreased flexibility of the arteries or less effective vasomotor control. It emphasizes the fact shown by experience that the best age for flying is the early twenties—a man of 36 has already begun to grow old.

Preliminary blood pressures: Reclining, 124; standing, 132; after exercise, 142; and two minutes later, 124.

During the test the systolic pressure rises at the start and remains at about 160. As often happens when systolic is high, there is not a very marked rise in pulse. There is no evidence of circulatory fatigue, and he reaches a low oxygen percentage with excellent command of his faculties. His present performance is first class, but it is unlikely that he would remain in condition long if he runs such a blood pressure when he flies. Class B.

evidence of circulatory fatigue after the flight. The vasomotor tone fell in at least 65 per cent of the men; in some the fall was slight, but in several instances it exceeded 30 per cent. In view of the limited amount of field study of the aviator and the fact that the flying has been at comparatively low altitudes, final conclusions can not yet be made. From the data available it appears that low flying fatigues the circulatory mechanism, but not, however, as much as the same time spent in physical work.

THE HEMOGLOBIN WHEN UNDER A DECREASING OXYGEN SUPPLY.

Since an increase in the percentage of hemoglobin in the blood is one of the most important of the low oxygen compensations found to occur in men and animals living at high altitudes on mountains, it is interesting to find that it may also occur during short exposure to low oxygen. The rebreathing test of not more than 30 minutes duration is too short a period of time to permit a concentration of hemoglobin in the majority of men. Only an occasional subject may show a definite concentration. In order to test out the part that the blood changes may play as a compensatory factor for oxygen want in such a short period as the aviator spends in the air, a series of experiments are now being made in the pneumatic or low pressure chamber and also under low oxygen. In these the subject is held at a chosen pressure or a given percentage of oxygen for from 40 to 90 minutes, the entire experiment lasting as much as two or two and a half hours. The hemoglobin has been determined by two methods, the Gower-Haldane hemoglobinometer and the Du Bousque colorimeter, on blood taken from a finger or an ear, and also from a vein in the arm.

At least 25 per cent of all men examined have shown a well-defined increase in the percentage of hemoglobin, and the majority some evidence of concentration. We have found that the blood from the finger or ear and from the vein showed it equally well by the two methods used in the determinations. The following illustrates the amount of concentration: Normal per cent of hemoglobin with the Gower-Haldane hemoglobinometer, from a finger 100, from a vein 90. After 80 minutes under low oxygen, 60 of which were spent at 10 per cent oxygen, finger 105, vein 102. The amount of concentration has been as great as 9.5 per cent. It has been most clearly induced at pressures, and percentages of oxygen, corresponding to between 18,000 and 20,000 feet. Almost all of the men have had to be held at the high altitudes 20 or more minutes before concentration began to be evident.

Since the blood changes do not always occur, and are slow in appearing when they do, the determination of hemoglobin during a rebreathing test has not been made a part of the routine examination.

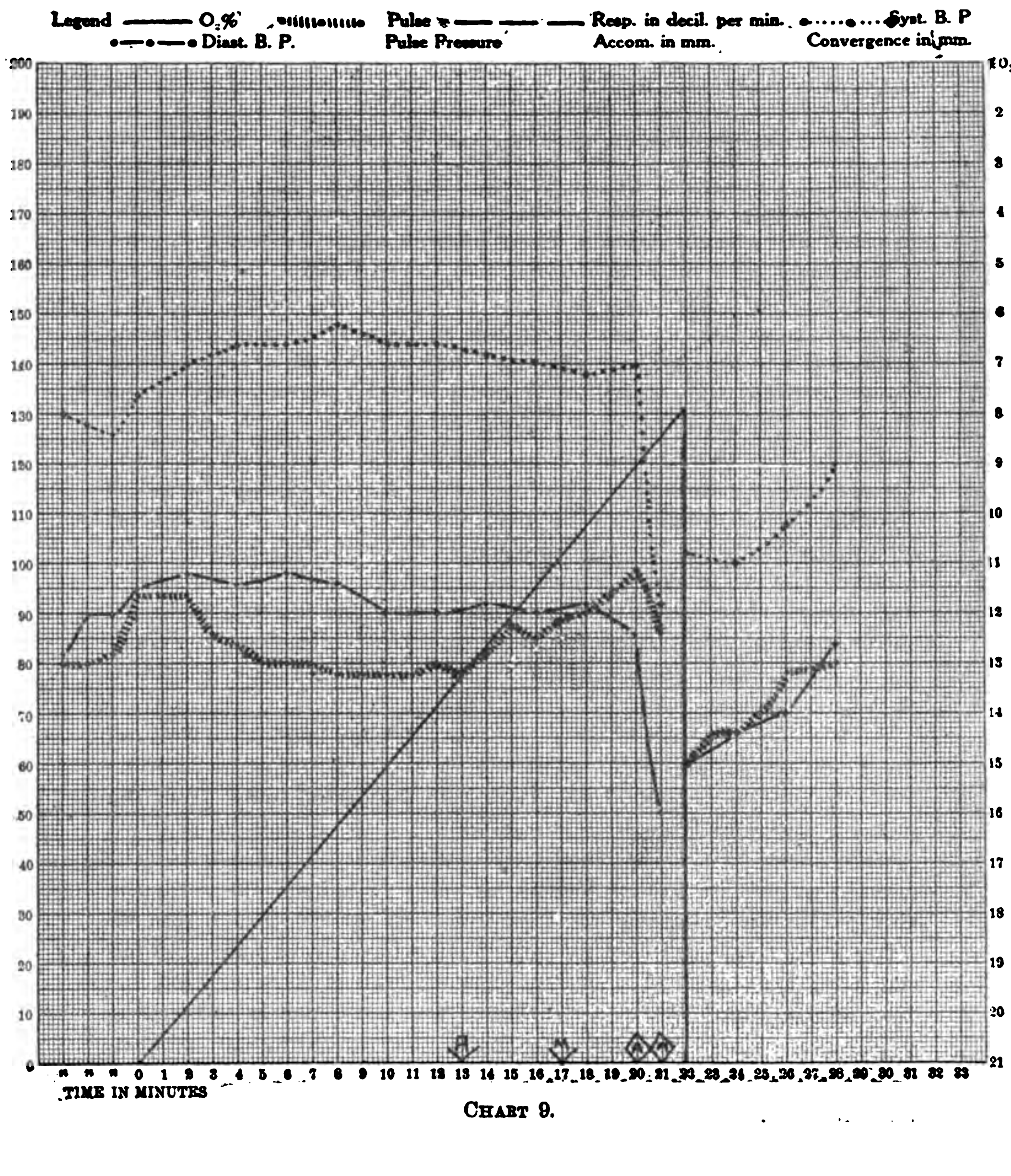

Legend —— O_2%
Pulse
Resp. in decil. per min.
Syst. B. P
Diast. B. P.
Pulse Pressure
Accom. in mm.
Convergence in mm.
% O_2
TIME IN MINUTES

CHART 9.

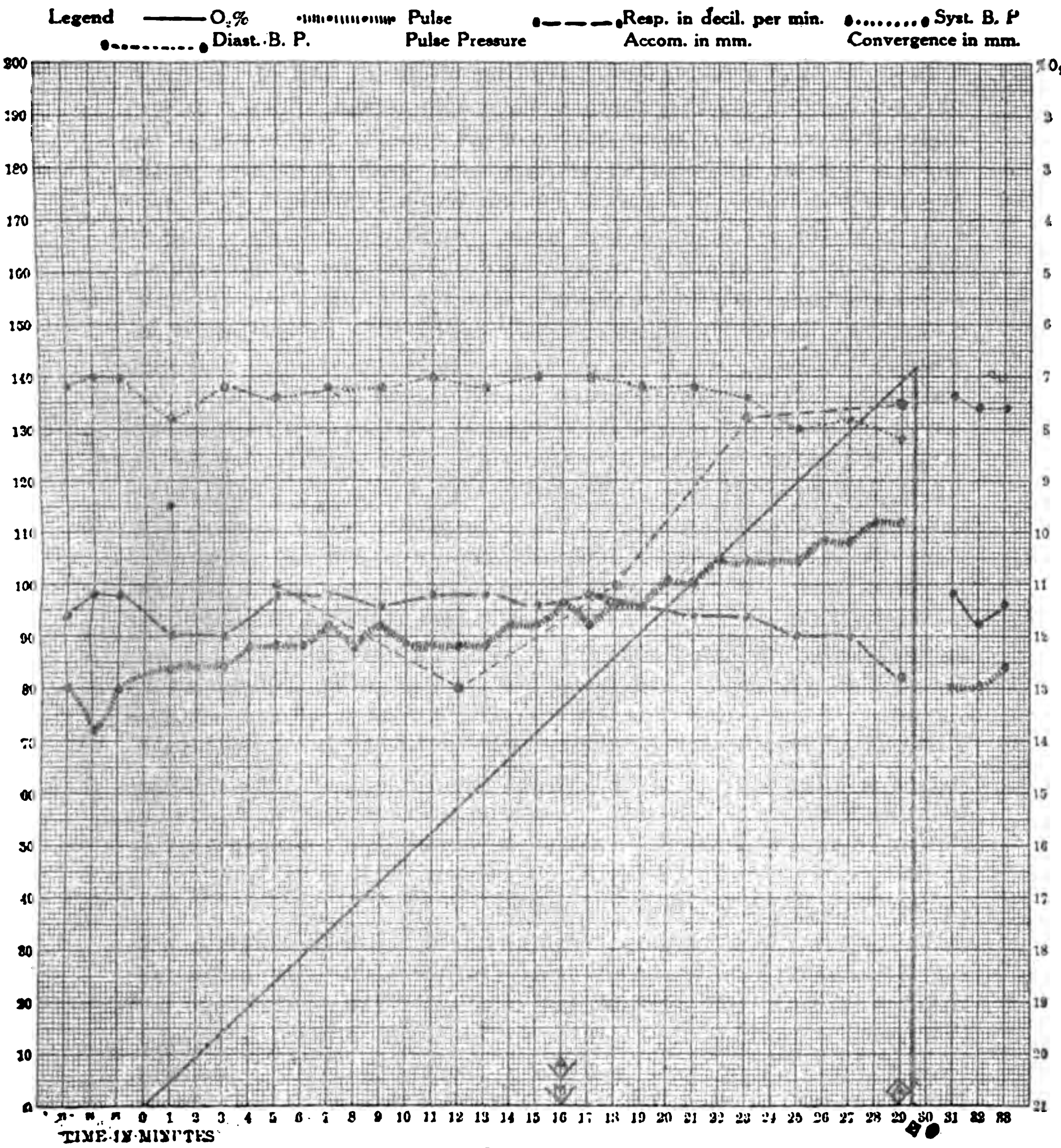


CHART 10.

No. 63.—J. E. S. CADET. Age 21 years 1 month.

Left hospital three days ago, where he was laid up for a week with influenza. Feeling fairly well to-day, though not up to his usual form.

The first chart is typical of a man out of condition, rather high systolic pressure, psychic rise in both pulse and pressure, followed by a sudden faint at about 8 per cent. In this the diastolic pressure fell practically to zero; the systolic pressure and pulse also broke sharply, as may be seen by the slow recovery after the experiment was terminated.

He was tested again two weeks later (chart not given), and made a very good run, with the exception of a rather high blood pressure (148). In this test he was not completely inefficient when taken off at 5.5 per cent. After two weeks he was given a third test (second chart), which entitles him to an AA rating. The systolic pressure stays below 140, there is no break in diastolic, and there is a moderate, healthy rise in pulse.

This case illustrates the very serious effects of temporary indisposition.

THE RELATIVE VALUE OF THE COMPENSATORY FACTORS.

In order that a better understanding might be had of the interplay of the compensatory factors, when man ascends quickly to very high altitudes and remains only a short time, a few hours at the most, a number of experiments have been made with men in the pneumatic chamber and also under low oxygen in which they have been held for an hour or two under conditions corresponding to altitudes of 15,000 to 20,000 feet. In all of these, two of the compensatory changes, those in breathing and in circulation, have appeared almost simultaneously and increased steadily with the gradually increasing altitude. When the desired altitude was reached and then maintained the breathing either continued at the depth it had acquired during the period of progressive change or it became still deeper for a time. The pulse rate, which gives an index of the increase in the rate of blood flow, accelerated during the period corresponding to ascent; and, then, when the altitude was held, usually remained constant, or, in some of the men, retarded somewhat after the hold began. A slowing of the pulse rate, when an altitude was maintained for a time, was so frequently observed that we sought for an explanation of the decrease in rate. In a number of men it was found that the heart was being relieved by other compensatory factors. In such cases one or the other or both of two changes occurred. There occurred either a further deepening of the breathing, or a concentration of the hemoglobin, or both of these changes took place together. Often the breathing, after increasing in amount during the ascent, held at a constant increased depth during the stay at the given altitude; but in such the hemoglobin was found to be concentrating as the pulse rate slowed.

An unusual but interesting case was found in a man whose breathing failed to respond to the changes in altitude. He did not tolerate the low pressure well at first, but felt better after some time had been spent at the chosen pressure. In this man the heart accelerated decidedly and later his hemoglobin concentrated about 8 per cent. His improvement occurred when the hemoglobin showed concentration.

As yet no attempt has been made to study oxygen secretion during our rebreathing experiments or in the pneumatic chamber.

Our studies show that during short exposures to high altitudes, or low oxygen, such as the aviator experiences, the compensatory reactions of the body to a decreased oxygen are made almost entirely by the circulation and by the breathing. A few men may, after the lapse of an hour or more, secure some benefit from a slowly developing concentration of the hemoglobin of the blood. The order of response by the adaptive mechanisms is not that of the good reaction

seen among mountaineers, in whom the breathing first responds while the other compensatory changes take place more slowly. The reaction resembles more nearly that seen during an attack of mountain sickness among mountaineers. In such men the heart beat is greatly accelerated during the attack. The aviator, it appears, must depend largely upon his heart and his breathing for compensation to the fall in oxygen which he encounters as he ascends.

The length of time taken to reach a low oxygen in the rebreathing test will profoundly alter the ability to endure extremely low percentages. If the oxygen is lowered rapidly, the candidate compensates to a lower percentage than is possible where the rate of decrease in the oxygen is slower. Three rebreathing experiments made on the same subject illustrate the condition. The volume of air was so small for the first test that in 23½ minutes the oxygen was lowered to 6.3 per cent, at which the subject's power of compensation failed. The next day, rebreathing a larger volume of air for 38 minutes, he compensated to 7 per cent only. On the following day, in a test of 85 minutes' duration, compensation failed at 8.7 per cent of oxygen. Individual differences will be found; in some men time has a more profound influence than in others. Thus, another subject compensated in a test of 36 minutes down to 7.5 per cent and in one of 90 minutes to 8 per cent of oxygen. Therefore, when testing ability to endure low oxygen, some allowance must be made for the time taken to reach a given percentage. If each of two men tolerate down to 7 per cent oxygen but one is carried down in 20 and the other in 40 minutes, the one who endures for 40 minutes will have the better power of compensation.

Control tests have been conducted in the pneumatic or low-pressure chamber to determine the reliability of the rebreathing test. A subject was first under observation in a rebreathing test, and on the following day taken into the low-pressure chamber for similar observations, while the pressure was lowered at the same rate that the oxygen had been absorbed in the rebreathing test. The breathing, pulse rate, and blood pressures reacted about the same in each experiment. In order that a comparison might be made of the breathing under the two conditions the alveolar air was analyzed from time to time during each kind of test. A fall in the alveolar carbon dioxide and oxygen pressure occurred in both experiences. The average amount of fall for eight men at the per cent of oxygen or pressure corresponding to 20,000 feet was for carbon dioxide during rebreathing 8.5 millimeters and low pressure 9.3 millimeters; for the oxygen in rebreathing 66.2 millimeters and low pressure 68.8 millimeters. These figures show that the increase in the breathing and lung ventilation was about the same under the two different low-oxygen experiences. The pulse rate also was found to begin to accelerate at about

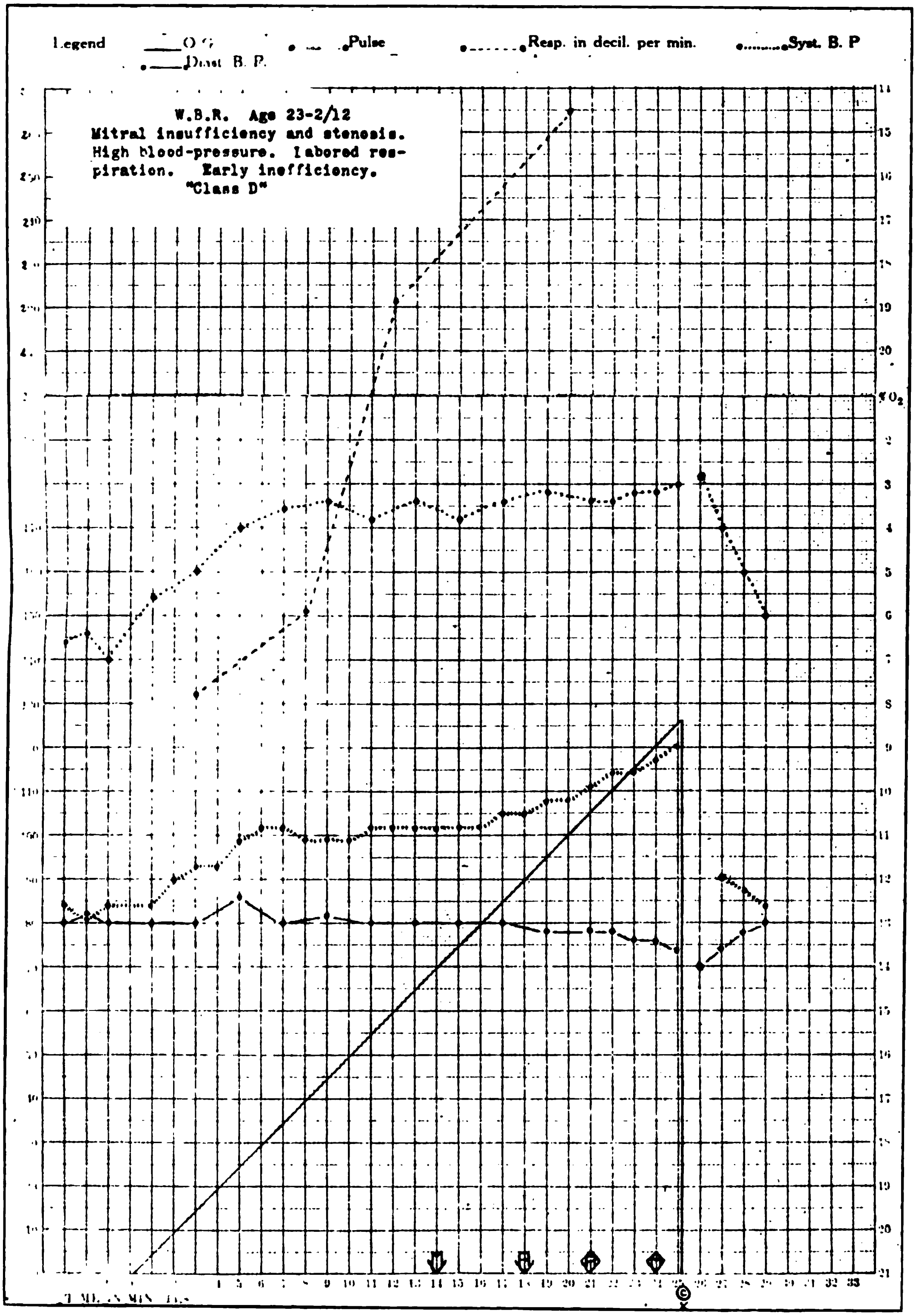
the same time in each kind of test and to accelerate in equal degree. Those and other physiological observations made on men undergoing the rebreathing test or under decreasing atmospheric pressure prove that the same compensations are used by the body in each, and those we know are the adjustments made to the influence of oxygen want.

ALVEOLAR AIR PRESSURES IN THE LOW PRESSURE CHAMBER AND ON THE REBREATHING APPARATUS.

Whether the individual is in the low-pressure chamber or on the rebreathing apparatus he can equally well be subjected to gradually decreasing oxygen pressure. The rebreathing machine has been shown to be equivalent to the low-pressure chamber for testing the ability of an individual to adapt himself to low oxygen pressure so far as circulatory and psychological reactions are concerned. A consideration of the respiratory factors in each was necessary in order to complete the comparison. The respiratory factors to be considered are: First, the alveolar air pressures; second, the volume per minute and rate; third, the blood gases.

A series of experiments were carried out to show the changes in the alveolar air pressures during an ordinary rebreathing test lasting about 30 minutes, in which the subject was exposed to a fall of oxygen per cent from 20.96 to 9.8, or corresponding barometric pressures of 760 mm. to 350 mm. (20,000 feet). The subject was put on the rebreather and samples of the alveolar air were taken every 4 or 5 minutes until the end of the run. The time and the oxygen per cent of the rebreathed air were noted and the corresponding barometric pressure for each oxygen per cent determined. The same subject was taken into the low-pressure chamber a few days later and the barometric pressure was lowered according to the rebreathing schedule previously made. Alveolar air samples were taken at corresponding minutes and altitudes. Both series of alveolar air samples were analyzed with the Henderson-Orsat gas analyzer and the partial pressure calculated allowing 40 mm. Hg. for the tension of water vapor. The curves of each subject were plotted on the same chart.

The curves of the alveolar air pressures plotted (see chart 9A) from the data obtained in the low-pressure chamber and with the rebreathing apparatus are striking in their similarity. In many cases they practically coincide. The oxygen tension in the alveolar air of eight subjects on the rebreathing machine fell from 102.5 mm. Hg. to 36.3 mm. during runs from 760 mm. to 350 mm., or 20.96 per cent oxygen to 9.8 per cent. This is an average fall of 62.2 mm. for 20,000 feet (see Table 1). In 10 corresponding experiments in the low-pressure chamber the alveolar oxygen tension fell from 104.6 mm. to 35.8 mm. during the ascent to 20,000 feet. The average fall was 68.8 mm. (see Table 2).



Legend O2 Pulse Resp. in decil. per min. Syst. B. P Diast B. P.
W.B.R. Age 23-2/12
Mitral insufficiency and stenosis.
High blood-pressure. labored respiration. Early inefficiency.
"Class D"

In the previous eight cases, in which the alveolar oxygen pressure was determined on the rebreathing apparatus, the alveolar carbon dioxide pressure fell from 42.6 mm. to 34.1 mm., an average fall of 8.5 mm. (see Table 3). In the 10 corresponding cases in the low-

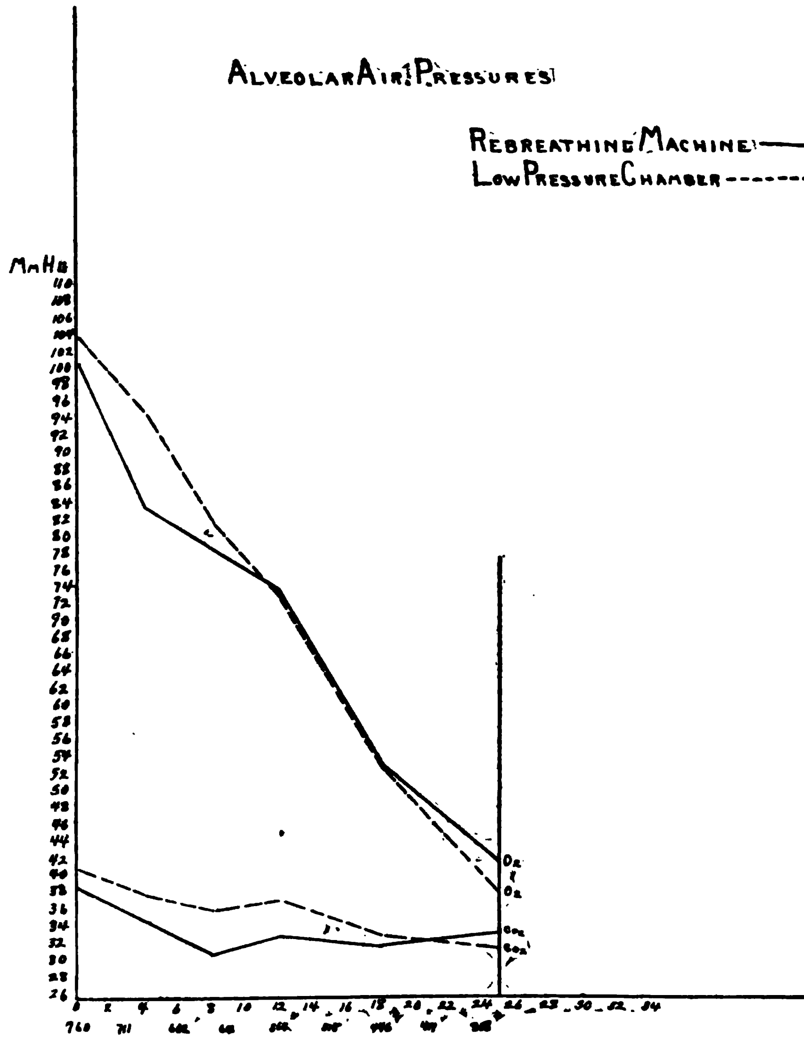


CHART 9A.

pressure chamber the alveolar carbon dioxide tension fell from 40.1 to 30.8 mm., an average fall of 9.3 mm (see Table 4).

The curve of the alveolar oxygen tension obtained in the low-pressure chamber or on the rebreather is essentially a straight line. That of the alveolar carbon dioxide tension is not so regular. Certain irregularities in the curve were found which could be correlated with changes in lung ventilation as indicated by the volume of air breathed

per minute. In seven cases there was a gradual fall of alveolar carbon dioxide pressure as the barometric pressure was lowered from 760 mm. to 350 mm. (20,000 feet). In two cases it remained nearly constant until about 550 mm. and then fell fairly rapidly.

An examination of tables 1, 2, 3, 4, and of the plotted curves shows very definitely that the changes of the alveolar air pressure during exposure to progressively diminished oxygen pressure are quite similar and that the respiratory factors as well as the circulatory and psychological reactions are the same in the two methods.

TABLE 1.—*Rebreathing* O_2.

Subject.	760 mm.	350 mm.
Griest	106.5	39.9
Browning	106.0	33.8
Pierce	103.0	39.0
Burlingame	109.0	38.0
Jenkins	97.5	24.0
Smart	99.0	38.0
Kuempel	97.5	36.0
McKinnie	101.2	42.0
Average	102.5	36.3—66.2

Average O_2 tension, 760 mm.	102.5 mm.
Average O_2 tension, 350 mm.	36.3 mm.
Average fall for 20,000 feet rise	66.2 mm.

TABLE 2.—*Low pressure* O_2.

Subject.	760 mm.	350 mm.
Neuswanger	116.7	33.4
McKinnie	104.2	38.0
Dorsey	94.5	34.4
Smart	92.0	36.0
Merrill	104.5	43.0
Kuempel	105.5	31.2
Jenkins	108.0	34.4
Burlingame	106.2	33.4
Leinbach	106.2	36.1
Pierce	108.7	38.7
Average	104.6	35.8—68.8

Average O_2 tension, 760 mm,	104.6 mm.
Average O_2 tension, 350 mm.	35.8 mm.
Average fall for 20,000 feet rise	68.8 mm.

TABLE 3.—*Rebreathing* CO_2.

Subject.	760 mm.	350 mm.
Burlingame	43.5	39.9
Browning	40.9	35.4
Greist	42.4	39.3
Pierce	43.1	32.6
Jenkins	45.6	18.0
Kuempel	43.8	34.8
McKinnie	39.2	33.0
Smart	42.5	39.8
Average	42.6	34.1— 8.5

Average CO_2 tension, 760 mm.	42.6 mm.
Average CO_2 tension, 350 mm.	34.1 mm.
Average fall for 20,000 feet rise	8.5 mm.

TABLE 4.—*Low pressure* CO_2.

Subject.	760 mm.	350 mm.
Smart	39.8	37.2
Burlingame	41.2	34.7
Pierce	39.0	30.4
Jenkins	38.7	27.3
Kuempel	39.8	24.4
McKinnie	40.4	31.6
Leinbach	37.8	27.6
Merrill	40.0	29.7
Dorsey	44.4	30.8
Neuswanger	40.4	34.7
Average	40.1	30.8− 9.3

Average CO_2 tension, 760 mm. .... 40.1 mm.
Average CO_2 tension, 350 mm. .... 30.8 mm.

Average fall for 20,000 feet rise. .... 9.3 mm.

From these preliminary experiments we should infer that in the ordinary short experiments in which the barometric pressure is lowered to about 350 mm. in 20 minutes, similar to the conditions during a rebreathing test, the alveolar carbon dioxide pressure starts to fall with the barometer. The law of Haldane and Preistly, which states that during rest under ordinary conditions the alveolar carbon dioxide pressure remains constant, holds good only when the barometric pressure remains constant also. These experiments point to the view that the alveolar carbon dioxide pressure does not remain constant under progressively diminished barometric pressure to the extent formerly believed.

A few men were taken to 15,000 feet at the rate of 1,000 feet per minute, held there for five minutes and then dropped at the same rate to 2,000 feet. This procedure was repeated three times in succession. The alveolar gas pressures were remarkably constant for the same altitude in each of these cases. Table 5 gives the result in two such cases.

TABLE 5.

Barometer.		760 mm.	425 mm.	700 mm.	425 mm.	700 mm.	425 mm.	760 mm.
1	O_2	104	40	91	40	92	39	98
	CO_2	41	39	43	39	41	39	42
2	O_2	106	51	96	47	95	48	95
	CO_2	41	29	34	32	36	30	41

In a number of experiments the subjects were exposed to low oxygen tension for longer periods. When the individual is held for an hour or more at a low barometric pressure, 380 mm. for example (18,000 feet), the alveolar air pressures tend to remain remarkably constant. In 10 cases the average alveolar carbon dioxide pressure at the end of 96 minutes was only about 1 mm. lower than when the low barometric pressure was first reached. The fact that there was no striking change in alveolar carbon dioxide pressure during prolonged exposure to a given low barometric pressure led us to examine the volume of air breathed per minute during these exposures and the carbon dioxide capacity of the blood at the beginning and at the end.

Eight experiments were carried out to determine the volume of air breathed per minute. The subject wore an American Tissot mask and inspired through a gas meter. The resistance of the meter was not great enough to cause any change in the rate or volume of respiration, as shown by control runs for periods of one to two hours. The average volume breathed per minute at 760 mm. was 7 liters. With the ascent to 380 mm. an increase in ventilation took place, attaining its maximum about 10 minutes after the low barometric pressure had been reached. In six cases of these eight the lung ventilation decreased more than a liter while the low barometric pressure was being held. In several cases the breathing decreased to its original volume before the ascent. During these exposures the type of breathing frequently changed from shallow rapid to slow and deep respiration. In one case the rate fell from 14 per minute to 9 within 20 minutes after reaching 380 mm.

During short exposures to progressively diminishing oxygen pressure with either the rebreather or in the low-pressure chamber the lung ventilation increases. In the rebreathing experiments the first respiratory response has been found to be between 16 and 14 per cent of oxygen. In the low-pressure chamber in a few experiments the response in breathing occurred at about 8,000 feet, or at approximately 15 per cent of oxygen. In several instances, however, the response began immediately.

CARBON DIOXIDE CAPACITY OF THE BLOOD.

Both on the rebreathing apparatus and in the low-pressure chamber the carbon dioxide capacity of the blood was determined before the experiment and at the end, while the subject was still under the influence of low oxygen. On the rebreathing apparatus 12 cases were examined, some of which reached 6.2 per cent of oxygen and showed a marked respiratory reaction. There was, however, no noticeable lowering of the carbon dioxide capacity of the whole blood as determined by the Henderson method. Even in the low-pressure chamber, where the subject was exposed to a pressure of 380 mm. for periods of over an hour, no decreased alkalinity of the blood could be detected. This is not surprising in view of the fact that the volume per minute breathed was lowered at the end of these experiments.

HEMOGLOBIN CHANGES.

One of the factors which compensate for prolonged exposure to low atmospheric pressure has been shown to be the hemoglobin. On Pike's Peak a relative increase in the per cent of hemoglobin takes place, which is later superseded by an actual increase in the number of red cells. The ordinary rebreathing test is too short to permit of a concentration of hemoglobin, but in experiments in the low-pressure chamber, where the subject is held for periods of an hour or two,

a well-defined increase has been found with the Gower-Haldane hemoglobinometer in blood taken from the finger and from the vein in more than 25 per cent of the cases examined. In several cases the amount of increase was more than 6 per cent and in one case as high as 9 per cent. In a few instances the number of erythrocytes was determined and an increase found, which in one case was 9.6 per cent and in another case 14 per cent.

CHANGES IN PULSE RATE DURING EXPOSURE TO LOW OXYGEN PRESSURE.

In a series of experiments in the low-pressure chamber, in which the barometric pressure was lowered to 380 mm. (18,000 feet) at the rate of 1,000 feet per minute and held at that altitude for periods varying from 60 to 104 minutes, the pulse rate was taken every minute during the procedure. The curve of the pulse changes plotted against the variation in the barometer, and time shows that the rate increases as the barometric pressure decreases, but does not maintain its maximum during the hold at the high altitude.

In 18 cases out of 20 there was a slowing of the pulse rate while the low pressure was being maintained. The average pulse rate at 760 mm. was 73 per minute. During the ascent to 380 mm. the average increase in the pulse rate was 19 beats, or about 1 beat per 1,000 feet. This increase in the pulse rate began between 2,000 and 3,000 feet in an average of 34 cases. In only 4 cases did it appear as late as 8,000 feet. In no other case was it above 4,000 feet.

The maximum pulse rate was reached in 24 minutes after the beginning of the ascent, or 6 minutes after the barometric pressure of 380 mm. have been attained. During the hold of this altitude, averaging 86 minutes, the average pulse slowed to 84 beats per minute, an average drop of 8 beats. The individual decrease in pulse rate varied from 5 to 14 beats and in 7 of the 20 cases it was 10 beats or more. (See Table 6.)

TABLE 6.—*Change in pulse rate during exposure to low oxygen tension.*

Experiment.	Normal.	Maximum.	Time reached.	Maximum.	Time reached.	Fall.	Total time.
1	64	91	23	81	62	10	81
2	70	94	31	86	76	8	82
3	65	102	26	102	49	1	64
4	88	99	25	93	81	6	104
5	75	89	30	83	72	6	86
6	72	87	22	82	82	5	92
7	71	86	20	78	75	8	91
8	73	93	22	81	75	12	77
9	78	94	22	80	35	14	61
10	74	120	24	106	56	14	68
11	69	87	27	78	85	9	96
12	80	100	22	90	54	10	65
13	59	80	22	70	72	10	78
14	60	82	24	74	77	8	79
15	81	88	22	82	64	6	78
16	95	99	25	99	80	....	85
17	67	90	28	84	72	6	78
18	76	88	26	81	81	7	100
19	72	94	24	89	68	5	71
20	76	82	22	71	68	11	91
Average	73.25	91.80	24.35	84.0	69.2	7.8	85.75

THE RELATIVE VALUE OF THE COMPENSATORY FACTORS.

The factors which are involved in the compensation during very long exposures to low-oxygen pressures, as on Pike's Peak, have been shown to be, first, the circulation, as indicated by the pulse rate and the blood pressure; second, the respiration, as shown by the rate, volume per minute, carbon dioxide and oxygen pressures in the alveolar air, and the carbon dioxide capacity of the blood; third, the hemoglobin; fourth, secretion of oxygen by the lung epithelium. Evidence bearing on the nature of the first three factors has been secured in these experiments. There is undoubtedly a considerable amount of coordination and interplay of the various factors. In the rebreathing tests the circulation responds first, later the respiration. In these tests the subject is pushed until he shows signs of failing in compensation. The situation is different when the individual is kept at a given low pressure in the pneumatic chamber. Both the pulse and the respiration accelerate during the ascent, but in a great many cases the pulse rate falls while the chosen pressure is being maintained. We should look for compensation by other factors in these cases, either by means of increased lung ventilation, concentration of hemoglobin, or possibly secretion of oxygen through the lung epithelium. In a number of men the heart was relieved by further deepening of the breathing or a concentration of the hemoglobin, or both changes occurred. A number of cases have been observed in which a concentration of hemoglobin took place while the heart rate slowed (see chart 10A), and the lung ventilation either maintained its own or became less.

An unusual but interesting case was found in a man whose breathing failed to respond to the change in altitude. He did not tolerate the low pressure well at first, but later his condition improved while the given low pressure was being maintained. The heart rate accelerated markedly and later his hemoglobin concentrated above 8 per cent. His improvement occurred when his heart was relieved by the concentration in hemoglobin.

Our studies show that during short exposures to high altitudes or low oxygen, such as the aviator experiences, the compensatory reactions of the body are made almost entirely by the circulation and the breathing. Some men may secure some benefit after an hour or more from a slowly developing concentration of the hemoglobin of the blood. The order of response by the adaptive mechanisms is not that of the good response seen among mountaineers, in whom the breathing first responds while the other compensatory changes more slowly occur. The reaction resembles more nearly that seen during an attack of mountain sickness among mountaineers. In such men

the heart beat is greatly accelerated during the attack. The aviator must depend largely on his heart and his breathing for compensation to the fall in oxygen pressure which he encounters during an ascent.

III.—THE EFFECTS OF LOW ATMOSPHERIC PRESSURE ON THE CIRCULATORY SYSTEM.

It has long been recognized in an unscientific way that high altitudes are "bad for a weak heart." At such elevations as those of Denver, Phoenix, or Mexico City, patients with any degree of cardiac incompetence noticed undue shortness of breath, palpitation, general weakness, and occasionally there have been cases of sudden decompensation and acute pulmonary congestion. Even much lower eleva-

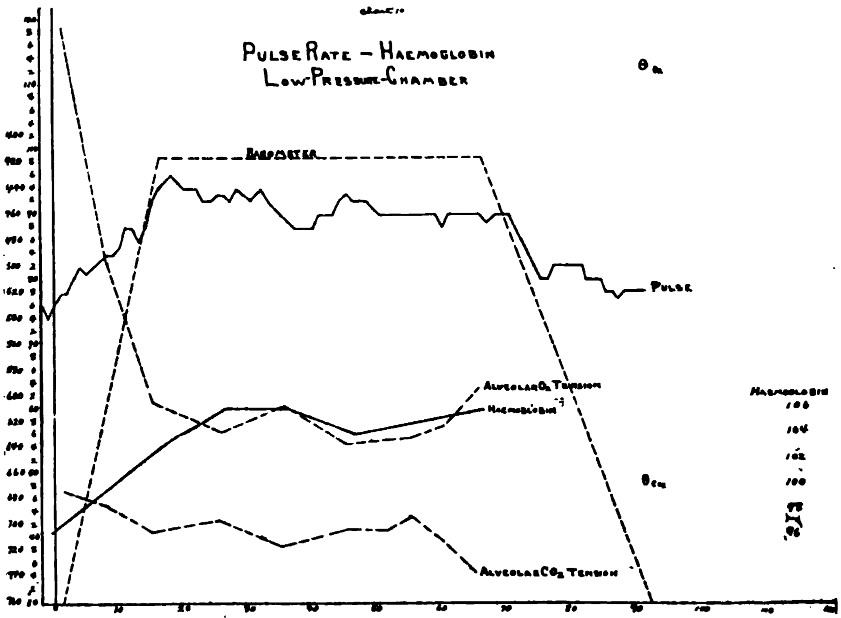


CHART 10A.

tions have been suspected by the laity of causing distinct heart symptoms. The reason for this has not been understood, because very little research work from this point of view has been carried on. The physiological results on Monte Rosa, Pike's Peak, etc., have had as participants and subjects almost entirely healthy men of the mountaineering type, and in these there has been so little evidence of circulatory strain, to say nothing of actual incompetence, that it was generally assumed that the supposed dangers from the heart were mythical or at least much exaggerated.

As a part of the research now being carried on at the Medical Research Laboratory of the Air Service at Mineola the behavior of

the heart and circulation has received much attention. We have had almost ideal conditions for this study, having at our disposal two methods of producing physiological effects comparable to those of aviation. In these effects the determining factor is, of course. low-oxygen tension in the air.

In the rebreathing apparatus the percentage of oxygen is gradually lowered, while in the low-pressure chamber the percentage remains the same, but the barometric pressure may be reduced to any desired point. In either case accurate observations of heart and circulation are conveniently made. The two methods give strictly parallel results, which tally very accurately with actual conditions in the air as far as it has been possible to investigate the latter directly or to judge from what is told by aviators of their own experience. The material studied has consisted largely of healthy and youthful individuals, though even among supposedly normal men not a few pathological hearts have been discovered, and from the neighboring post hospitals we have obtained a few subjects who were known to have definitely abnormal hearts. In the near future we hope to extend very considerably our observations on the grosser forms of valvular and myocardial disease and on cases with various degrees of decompensation.

The results have been exceedingly interesting and important and have so fitted in with the experiences and the problems of aviators that they can not but be of the greatest practical value. They have shown that the ability to exist at altitudes higher than the normal depends to a very marked degree on the competence of the circulatory apparatus. The demand on the latter is so great that even slight abnormalities in heart or blood vessels result at moderate heights in clear signs of cardiac insufficiency and distress. So searching indeed is this test for cardiac disease of any kind that we have come to regard the rebreathing apparatus and the low-pressure chamber as the one sure way of making a positive diagnosis in cases where there is doubt, and believe that they may later prove to be of great value for routine clinical work.

At the same time the effects upon the normal heart have been equally striking and more unexpected. While the hardiest type of subject shows almost no demonstrable effect on the circulation, others are evidently laboring under heavy strain, and it appears that dilatation of the heart followed by collapse is an extremely common occurrence even at moderate altitudes. This accords with the known frequency of aviators fainting in the air, almost always with fatal results, of course. We have been able to throw much light on the reasons for this disastrous occurrence, and to show not only that evident disturbances of heart function, such as cardiac lesions, are predisposing causes, but that temporary indispositions which are too fre-

quently considered trivial have a very marked influence. For example, a recent infection, a bad cold, nervous factors, etc., may so impair a man's resistance that his heart will give out and he will faint during the test. We believe that this has actually occurred in numerous cases during actual flight.

It has been estimated in the British Service that of all fliers lost to active flying service less than 2 per cent are put out by German bullets, only 8 per cent as the result of a defect in the plane, the remaining 90 per cent because of the physical condition of the pilot. Our work leads us to believe that a considerable proportion of the physical defects leading to accident are the immediate or late effects of strain on the circulation under the influence of low oxygen tension in the air.

PHYSIOLOGY OF CIRCULATION.

The purpose of the heart and blood vessels is to transport oxygen and food to the tissues and to remove their waste. The work of the circulatory system must be governed by the changing needs of the tissues in these respects. If a given group of muscles, for example, are doing more than their usual work they must have an increase of blood supply. This regulation comes mainly from the vital centers in the medulla, and consists for the most part in variations in the size of blood vessels (vasomotor tone), in the rate of the heart, and in the amount of lung ventilation. The medullary centers are in turn activated by certain chemical factors in the blood, and probably also more directly by their own metabolism and need for oxygen.

The work done by the heart is very large even when the body is at rest. It has been calculated that this amounts in ordinary conditions to the work involved in lifting 20 kilogram one meter each minute or about 140 pounds 1 foot. During exercise this work is, of course, much increased.

Apart from the strain thrown upon the heart by extraordinary demands it is evident that even its ordinary work requires the best of conditions to be carried successfully. Heart failure may be the result, therefore, not only of extra work asked of the heart, but of any condition which interferes with its success in doing its ordinary work.

The efficiency of the heart depends, first, on the quality of the heart muscle; second, on an abundant coronary circulation, capable not only of supplying ordinary needs, but of meeting the demand for considerable increase; third, on the quality of the blood which nourishes the heart muscle, especially its content in oxygen; and fourth, on an economical regulation of the work of the heart and of all of the elements in circulation and respiration, so that these functions may be carried out successfully, but without unnecessary strain. The

last factor depends partly on the accuracy and economy with which the need for blood flow to each part of the body is met, and partly to the regulation of general vascular tone, so that the blood flow can take place to the maximum of efficiency without undue resistance (increased blood pressure).

EFFECT OF LOW OXYGEN TENSION ON CIRCULATORY PHYSIOLOGY.

The behavior of the organism under low pressure illustrates two physiological principles:

First, that the animal body being very accurately fitted for one set of environmental conditions, finds itself in an abnormal situation if these conditions are changed ever so slightly. We know that the body feels the change in its oxygen supply within the first few thousand feet, perhaps even the first few hundred feet after ascent begins from the surface of the earth. In consequence of this certain readjustments and compensations are necessary to keep the oxygen tension in the air.

The second principle is that however accurately the body is adjusted to its usual surroundings, its powers of accommodation to new conditions are very great, even when those conditions represent something quite out of the ordinary experience of the body. Thus when adjustments are demanded to make good oxygen deficiency in the atmosphere, such adjustments almost infallibly will be made and in sufficient abundance to keep bodily functions normal until the change from usual conditions has become so great that the powers of compensation are exhausted.

In other words, the aviator making an ascent to great heights gives the picture not of a man suffering more and more severely from the noxious effects of low oxygen but of a man who by exercising his powers of compensation is keeping his functions normal just as long as these powers remain equal to their task.

It was in fact a good deal of a surprise to us to find this unexpected normality of our subjects in the early experiments, for not only were the physical and psychic powers being kept intact until an extreme degree of oxygen want was reached, but the adjustment was so smoothly and economically made that our examination of heart and blood vessels and the respiratory phenomena would have led us to suppose that nothing out of the ordinary was going on at all.

This statement applies, however, only to what we may refer to as the "optimum" type of subject, and it was only by observing the behavior of less good subjects that we arrived at an understanding not only of the nature of the compensation which was making this normality possible, but of the very great strain which is often involved in maintaining it. For while our optimum subjects remained

in good condition and efficient to very great heights and at t
time exhibited no signs of strain in the circulatory reaction
subjects either failed to make the compensation and so beca
efficient at low altitudes or made the compensation only at tl
of very evident strain, such as led in many cases to cardiac dilat
circulatory collapse, and fainting.

COMPENSATION FOR OXYGEN DEFICIENCY.

We must first discuss the nature of the compensating process and later consider how different types of organisms respond to this demand.

When the tissues feel a deficiency in the oxygen supply, demand is immediately registered for more. Just how this deficiency is felt and what the nature of the demand is we need not discuss at this point. (As a matter of fact, we have very little knowledge on the subject.) It is sufficient that such demand is made and that it is promptly complied with.

When there is deficiency in the oxygen carried by the blood there are two obvious methods of remedy open—either (*a*) more oxygen must be carried by the same amount of blood or (*b*) more blood must flow to the tissues carrying less oxygen per unit but in sum bringing the required amount.

INCREASED RESPIRATION.

To meet the demand of (*a*), if the blood carries less oxygen per unit because of lowered tension in the alveolar air, this tension may be raised by increased ventilation of the lungs. Normally the percentage of oxygen in the alveolar air (that which comes in contact with the blood) is from 13 to 15 per cent, giving a tension of 100 or more mm. Hg. Increased respiration will raise this percentage to 17, 18, or even 19, thus increasing the oxygen tension in the blood to a like degree. In fact, we know that increase in respiration begins to occur almost as soon as the sea-level pressure is left behind.

The limit of compensatory mechanism is soon reached however. Since the atmosphere contains only 21 per cent oxygen, the alveolar air can only with difficulty be brought up to 19 per cent, and an increase from 15 to 19 per cent will certainly not compensate for a drop in atmospheric pressure of one-half, such as occurs when a height of 18,000 feet has been reached.

INCREASED BLOOD FLOW.

The second method will be more productive of results. Instead of providing the normal amount of blood with the usual burden of oxygen an increased blood flow with a lessened amount of oxygen per unit will answer as well.

Increased blood flow is accomplished in two ways. There must be peripheral relaxation of the arteries to allow more blood to pass, and there must be increase in the amount of blood coming from the heart. The latter is accomplished either by increase in pulse rate (more beats per minute delivering the normal volume) or by increase in volume output per beat. Increase in heart output by either method would, of course, tend to raise the blood pressure.

It may be emphasized that a very considerable increase, possibly a doubling, of the blood flow may be accomplished with very little evidence that this is taking place, since the various mechanisms for accomplishing it interplay in such a fashion as to hide each others' traces. Thus increase of pulse may be made unnecessary by increase of volume per beat (it is, however, still a controversial question how much the latter can vary). Again, increase of heart output must, of course, raise the blood pressure, while decrease in peripheral resistance (vasodilatation) lowers it again. We have reason to believe that for a given organism a certain blood pressure is optimum, combining efficiency with economy, and that the body tries to keep to this pressure as closely as possible. For this reason the best type of subject will show almost no change in either systolic or diastolic pressure until late in the experiment, when the powers of compensation are being pushed to the limit.

RELATION OF VASOMOTOR CONTROL OF THE HEART.

A thorough understanding of the interplay between heart and blood vessels is necessary in order to comprehend the adjustment and failures of adjustment occurring on exposure to low oxygen. In everyday life this interplay is constantly going on; the better the condition of the heart muscle and of the arteries and the better the nervous control the more successful will the organism be in keeping up its efficiency. Every effort, such as rising from a chair or running for a street car, even every emotion, calls for increase of blood flow and would inevitably give rise to increase of blood pressure and extra work for the heart if vasodilatation did not ease the strain and at the same time allow the increased flow. A young man with good arteries can exert fairly violent muscular efforts with moderate and transitory rise in pulse and blood pressure. An older man, however, whose arteries are less flexible, can not do this. In his case the blood pressure may increase to a dangerous point because of failure of the peripheral tone to relax. The result of this failure will be either that the heart is put upon a dangerous strain or that the demands are simply not met. In the latter case the organism will for the time being have to run with a deficit; hence loss of efficiency and symptoms of deficient circulation (dyspnea, cyanosis, weakness, etc.).

NERVOUS FACTORS IN VASOMOTOR CONTROL.

The nervous element in the control of the vasomotors is of great importance. It is well known that the vasomotor system is the most sensitive part of the body. The slightest emotion will cause flushing or pallor, or even an anemia of the brain, which leads to fainting. The nervous regulation is especially under the influence of lack of "condition" from various causes, such as infections, indigestion, lack of sleep, etc. If a man is out of condition a slight effort will cause twice the rise in pulse and blood pressure that it normally should, and this rise will last much longer.

There are observations to show that purely nervous factors, such for instance as great mental concentration, will cause a higher and more lasting rise than severe muscular exertion. This is presumably because in physical exertion vasodilatation will provide for the extra blood flow needed with very little necessity for increasing the blood pressure. Where nervous tension is at a high pitch, however, the vasomotors are certain to share in this tension. Peripheral resistance will be high and the blood pressure will be high and sustained. Pressures of 200 have been observed in young men as a result of mental work or excitement, and such a pressure may last for an hour or more, often until peripheral relaxation has been brought about by such means as vigorous muscular exercise, a hot bath, etc. We shall see later that this psychic reaction of peripheral vascular tension (and of increased heart rate as well) has a marked influence on the ability to withstand low oxygen.

In the normal organism the amount of blood flow will not only be regulated as to total amount, but there will be accurate division according to the needs of the various parts of the body.

The aviator is not using his muscles to a great extent, so does not need a great increase in blood flow here, though the deficiency in oxygen is probably felt to some extent in all the tissues and the blood flow to all parts of the body may need to be increased somewhat. Two parts of the body however, must be especially taken care of—the brain centers which feel the want of oxygen and are regulating its supply and the heart muscle which is doing more than its ordinary work. It is probable that one important difference between the "optimum" type and the type who overcompensates and strains his circulation is that the former keeps brain and heart well supplied with blood but does not flood the rest of his body, while the latter has a marked increase of flow to all parts and so throws this unnecessary extra work upon the heart.

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FAILURE TO COMPENSATE.

It has already been suggested that when circumstances arise calling for a compensation involving heart strain certain hearts will respond with the necessary effort even to their own detriment, while certain others will give up the task at once and allow physical inefficiency to result. The difference is partly one of condition of the heart muscle and general physical tone, and partly of the quickness and efficiency of the nervous reactions which govern the vital functions. The same principle applies to the whole body, even to the personality, as well as to the heart alone. One individual will drive at business, athletics, etc., with an intensity which brings success. but often at the cost of health; another will save his health but lose the game or the business deal.

This conception is necessary in understanding the reaction to low oxygen. One subject will compensate fully with strain if it is necessary; the other will very early give up the effort and his efficiency will be correspondingly early impaired. Inasmuch as the strain is most vitally felt in the circulatory apparatus it follows that the subjects who are most vigorous in adjusting themselves to the new condition will show cardiac exhaustion, while those who show early inefficiency will not. Furthermore, a man who shows early inefficiency can still go on with the experiment, becoming more and more inefficient, but not straining his heart. The man who compensates, in other words, frequently gives out from heart or vasomotor exhaustion (faints) while the man who does not so compensate may remain more or less in possession of his faculties to a much higher altitude. This result seems paradoxical since the former class are individuals who are physically far superior to the latter.

INSUFFICIENT COMPENSATION.

It is to be assumed, of course, that no organism will fail to make any efforts to adjust itself to altered conditions. We have, however, encountered a few individuals whose reactions have been almost nil. Such men show no demonstrable rise in pulse, no change in blood pressures, and none in respiration. From this one could predict that the psychological tests (the best criterion we have as to the sufficiency of the compensation) will show early deterioration. We have observed " complete inefficiency " in a few cases as low as 6,000 feet (or at the corresponding oxygen percentage). Such men are usually constitutionally inferior, often undersize, with poor chests, poor color, clammy, mottled hands, poor complexion, etc.

In addition to these types of constitutional inferiority similar lack of reaction will be shown by many men, especially those toward middle age, who have led a sedentary life, are overweight and flabby,

perhaps with fatty hearts. In these cases it might be expected that a good course of physical training would much improve their reactions. It has long been recognized on Pike's Peak that the visitors of athletic type and in good training are much less likely than others to be mountain sick.

It is not to be expected that either of these types will commonly be found among a class so carefully selected as aviators. Less degrees of inability to compensate, however, are not uncommonly found. All these cases, of course, follow the rule that the less vigorous the compensation the less likely the subject is to show heart strain.

THE "OPTIMUM" TYPE.

At the other extreme is the "optimum" type for aviation, those who compensate fully to very great altitudes, retaining their efficiency and yet doing this in so accurate and economical a fashion from the point of view of the circulation that there is little or no evidence of strain. When the break comes (above 25,000 feet in the low-pressure tank, at from 5.5 to 7 per cent on the rebreathing apparatus) it comes with great suddenness; from almost full efficiency there is a quick lapse into unconsciousness, but still with no circulatory collapse. There is no loss of general muscular tone; the subject remains sitting with eyes open, stylus held firmly in hand, color full, though of course cyanotic, pulse full and regular, systolic and diastolic pressures maintained. Recovery is almost instantaneous on return to normal oxygen pressure and is complete. The subject usually refuses to believe that he has not been conscious and efficient throughout. We must attribute this unconsciousness to direct action of low oxygen on the cortical centers while the circulation is still in order.

CIRCULATORY COLLAPSE.

Quite different is the picture when circulatory failure has occurred; cardiac dilatation, sudden collapse of vascular tone, ashy pallor, cold sweat, complete loss of muscular tone, so that the subject always falls from his chair. Recovery is slow and unsatisfactory; it is often an hour before the man is himself again. Circulatory collapse may be seen at any stage of the experiment, depending on the amount of strain preceding it, and occasionally comes on most unexpectedly.

HEART STRAIN.

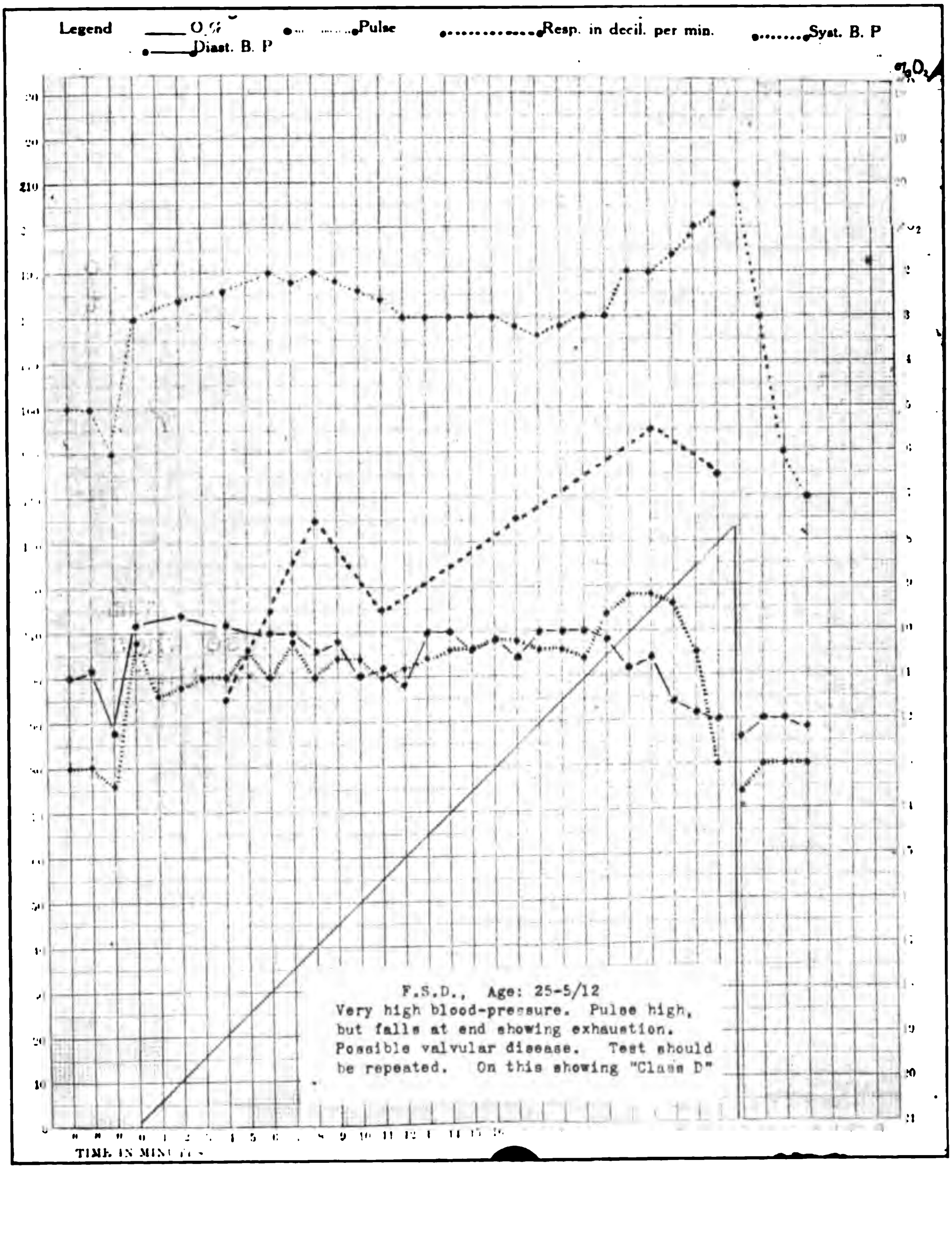
The syndrome of heart strain, followed by dilatation and fainting, is of very great importance in aviation. We know that fainting in the air is common and that such an occurrence is practically always fatal. We know also that aviators almost invariably develop in time

a disabling "staleness," which we strongly suspect is the result of this recurring heart strain, and that fliers who have "gone stale" are particularly sensitive to low oxygen and particularly liable to dilatation and fainting.

That heart strain is common was shown during a recent demonstration of the low-pressure chamber to a group of medical officers, men certainly of average health, though not in the best of training. Five men were taken into the tank and of these two had acute heart symptoms and had to take oxygen before 20,000 feet was reached. The following day five more men underwent the test; one had a dilatation at 14,000 feet, another at 16,000 feet, and a third at 18,000 feet. In other words, just half of a group of ordinary subjects showed this very striking effect. It was interesting that in each case the dilatation was demonstrated by percussion while the subject still felt perfectly well, according to his statement, but in each case he began to feel ill before a minute had passed and would have fainted if oxygen had not been given promptly.

Let us summarize what has already been said as the incidence of heart strain; the "optimum" subjects do not show it, either because they have a strong heart muscle or because their compensation is made so economically as to throw a minimum of work on the heart. The poor types of reactors (those whose compensation is of low grade) do not show it, because their hearts are not being asked to overwork. Subjects with defective heart muscle do not show it, because their hearts refuse to overwork. Those who do show it are young men of quick reaction, usually of excellent constitution, though often "out of condition." Such subjects often have a marked psychic reaction from the start, with rise in pulse and blood pressure, indicating undue tension of the nervous system. When one listens to the heart it is evident almost from the start that this organ is working too hard; at first, perhaps, with plenty of reserve, but later the limit is passed and there is a sudden break.

What is the essential difference between the "optimum" type and what might be called the "next to the optimum type," by which the one shows no circulatory exhaustion up to the point of unconsciousness while the other breaks? It is partly strength and quality of heart muscle and ability to stand strain; it is partly a smooth working of the nervous regulation of heart and blood vessels, including freedom from high nervous tension; it is partly the ability to furnish an abundant circulation through the coronary vessels when need arises. It can be expressed in one word familiar to physical trainers, "condition." If we knew just what "condition" means we should have the answer to the question above.


Legend ___ O₂% Pulse Resp. in decil. per min. Syst. B. P Diast. B. P
%O₂
210
10
TIME IN MINUTES
F.S.D., Age: 25-5/12
Very high blood-pressure. Pulse high, but falls at end showing exhaustion. Possible valvular disease. Test should be repeated. On this showing "Class D"

CONDITION.

We imagine the chief elements in athletic condition are a strong heart muscle, a highly efficient coronary circulation, and good peripheral vasomotor control. We may guess that there may be even deeper factors, such as a difference in the chemistry of the tissues allowing rapid metabolism, and the ability to generate energy rapidly without the accumulation of harmful end products. At any rate, our work strongly emphasizes the necessity for keeping aviators as nearly as possible in perfect physical condition and preventing them from flying when they are not so. We believe they should daily be made to exercise in such a way that the heart will have to work harder, the coronary vessels deliver a full volume of blood, the vasomotors be practiced in their work, the respiration deepened, and metabolism kept going at an increased rate.

TEMPORARY INDISPOSITIONS.

By "lack of condition" we mean not only "softness" due to lack of exercise, but many temporary indispositions, such as may follow a bad cold, recent illness, lack of sleep, overwork, alcoholic excess, etc. The influence of such factors on ability to withstand low oxygen was well illustrated by a subject who had been tested many times and found to be one of the hardiest we had met with. One day he was carried in the low-pressure chamber to an altitude of 22,000 feet and kept there about 15 minutes with almost no effect on his general efficiency or on his heart. That evening he dined with friends, drank a moderate amount of alcohol, and went to bed late. The following morning he felt rather giddy and had a slight headache. He was taken to 18,000 feet in the low-pressure chamber. At this point he had reached complete inefficiency by the psychological tests, was rather cyanotic, and examination of his heart showed the left border out 3 or 4 cm. If he had not been given oxygen at once or brought down quickly he would have fainted. It was fortunate for him that this occurrence took place in the laboratory and not while in an aeroplane thousands of feet above ground.

We can only speculate as to whether such differences in condition are due to variations in nervous control or whether they have a basis in the chemistry of the tissues. At any rate, such temporary lack of condition is a much more serious matter than we are tempted to believe. Athletic trainers recognize it clearly enough and would not allow such a man to participate in a game, not because he would injure himself, but because he would not hold up to the strain and might lose the game. In flying, where the aviator's life is at stake, equal care should be observed, to say the least.

PHYSIOLOGY OF EXERCISE COMPARED WITH AVIATION.

It must be borne in mind that the demand made upon the heart in aviation is widely different from that of physical exercise. The most obvious difference is that one call is familiar, and we are used to meeting it; the other is unfamiliar and requires delicate and accurate reflexes to sense it and to meet it properly.

In the body at sea level the regulation of the vital functions is largely activated by carbon dioxide or, more broadly speaking, by the chemical constitution of the blood. During exercise a large amount of CO_2 is produced, and at the same time other metabolic products find their way into the blood, so that respiration and circulation are stimulated to great activity. There is a great margin of safety in this method; long before CO_2 and other substances in the blood have risen to a toxic level the feeling of exhaustion is so insistent that further physical effort becomes almost impossible. For this reason circulatory collapse rarely occurs as the result of physical exertion.

In the case of aviation, on the other hand, no extra CO_2 is being found, and the low atmospheric pressure so reduces the partial pressure of the CO_2 in the blood that it exerts little, if any, regulatory action. The probability is that the activation of the vital centers in this case ceases to be a function directly of the constitution of the blood, but depends on the oxygen metabolism of the nerve-tissue itself. At any rate the margin of safety between the stimulating and the paralyzing effect of oxygen-want is very narrow, and since there is no dyspnea and distress preceding the final collapse, the latter comes on with no warning; hence its terrible danger to the aviator.

In exercise, again, there is a natural check against excess which is lacking in exposure to rarefied air. When exhaustion comes one is forced to rest, thus terminating the extra work for the heart and giving a chance for recovery. In the case of the aviator, however, exhaustion brings exactly the opposite result. If the heart falters for a moment, not only do the nerve centers run the risk of exposure to a paralyzing anoxemia, but the coronary circulation becomes insufficient, and on the fullness of the coronary blood supply depends the ability of the heart to do this work. Thus a vicious circle is started, and, once the heart has begun to fail, nothing can avert collapse. In exercise faltering of the heart means the opportunity to recover, in aviation it means a break in competence and dilatation, and probably death if the exposure were continued.

FAINTING.

Before leaving the subject of fainting it should be remarked that this occurrence is common at all altitudes, even the lowest. It occurs, of course, in ordinary life on the surface of the earth, not as a sequel

of heart dilatation, but as a vasomotor neurosis pure and simple. Evidently, however, since it occurs so very frequently in flying we can not consider it purely a neurosis or dismiss it as a psychic effect. We must say rather that it represents a demoralization of the vasomotor system in its effort to make the fine (even though not laborious) adjustments necessary to compensate for oxygen deficiency.

An interesting analogy may be drawn to writer's cramp and other occupational neuroses, which suggests an explanation for the occurrence of vasomotor phenomena, such as fainting during exposure to low oxygen. These neuroses are never found on the long continuance of fine muscular movements involving accurate coordination, as in writing, use of the typewriter, sewing, playing a musical instrument, etc. On this analogy it is easy to understand how the constant delicate adjustments demanded of the whole circulatory system during repeated flights at ever-varying altitudes may lead to demoralization of the vasomotor system even when the actual strain is not great.

For this reason we are inclined to class fainting as a low-oxygen effect even when it occurs near the earth. It is probable that the routine use of oxygen at the lowest altitudes would prevent a great deal of the fainting in the air. As our work has progressed we have become more and more impressed with the perfectly definite effects following exposure to altitudes below 5,000 feet. These results are usually not observed at once, but are cumulative, and are ordinarily seen only in aviators who have begun to "go stale." It is not sufficient, therefore, to bar a stale aviator from high flights; he should not fly at all.

EFFECTS ON PATHOLOGICAL CASES.

We shall now consider rapidly the behavior on low-oxygen tests of subjects with definite circulatory lesions of various types.

ARTERIOSCLEROSIS.

Individuals with stiff arteries give a very characteristic reaction. They illustrate very clearly that the physiological response to low oxygen has to begin at a very low altitude in order to preserve the normality of the body. Such subjects will show effects very early, both by their inefficiency and by the abnormality of their heart sounds. We have seen several who were "completely inefficient" at 8,000 feet, while at the same time the heart rhythm was hurried, the first interval shortened, and the first sound weak and valvular.

The essential difficulty with stiff arteries is that they will not play their part smoothly in bringing about increased blood flow and at the same time sparing the heart. For this reason, even in ordinary life, arteriosclerotics must continually be having sudden marked rises in blood pressure, the result of every exertion and every emotion.

The extra strain thus thrown on the heart must lead either to overwork of that organ or else to inefficiency.

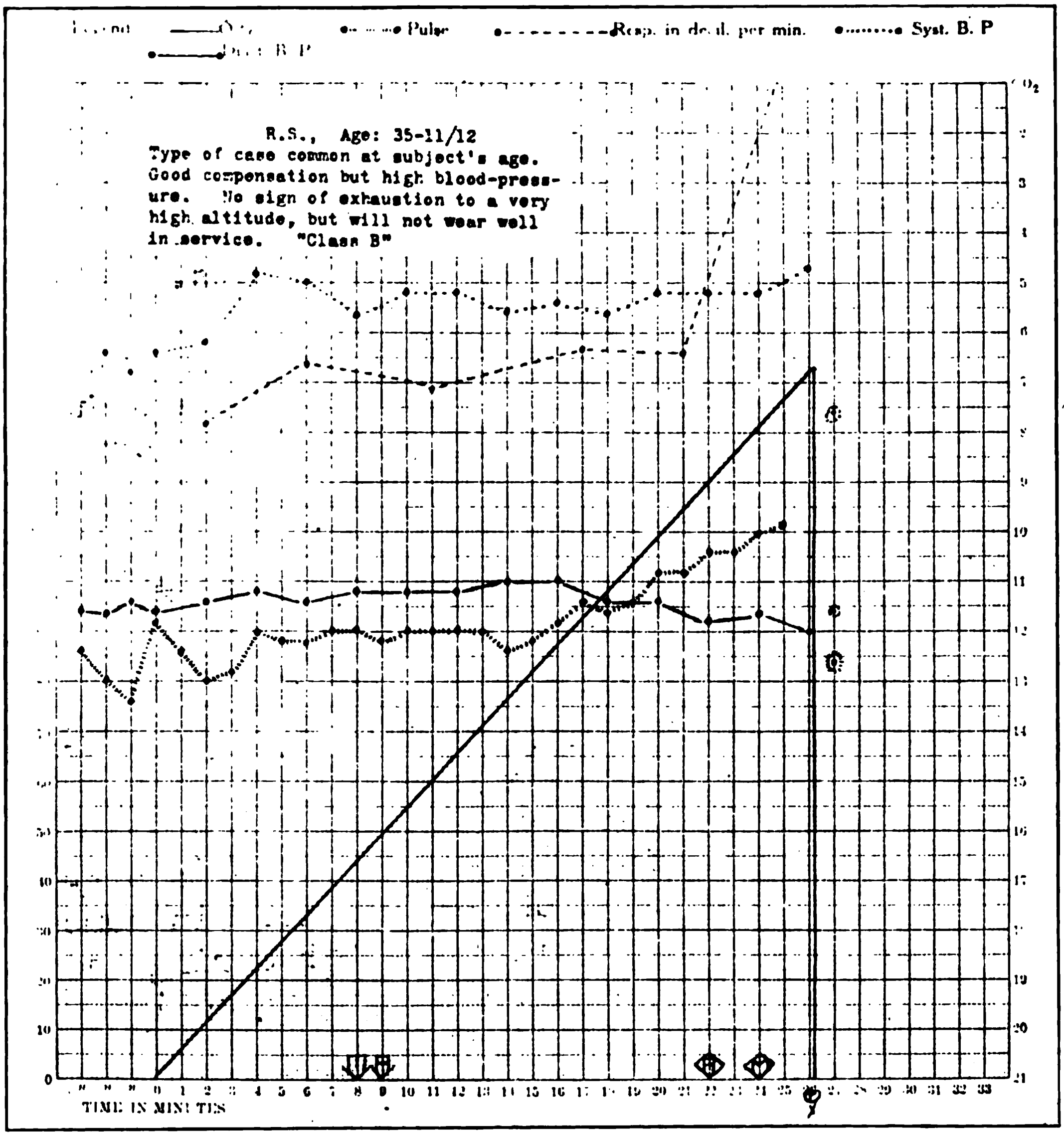
Nothing illustrates so well this lack of adaptability of old arteries as aviation. Almost immediately the blood pressure rises sharply. (We have observed a pressure of 180 in several perfectly healthy and vigorous older men.) At the same time the pulse accelerates. This strain has to be carried by the heart at a time when the coronary vessels, themselves sclerosed, are not furnishing the heart muscle the extra blood supply called for, and the blood that does come carries progressively less and less oxygen. Of course the heart can not meet the demand for more blood supply, and the work is simply not done. Such hearts do not dilate, in our experience, because they give up the task rather than overstrain themselves; at any rate, we have never dared to carry such a subject to a point where there was likelihood of cardiac dilatation.

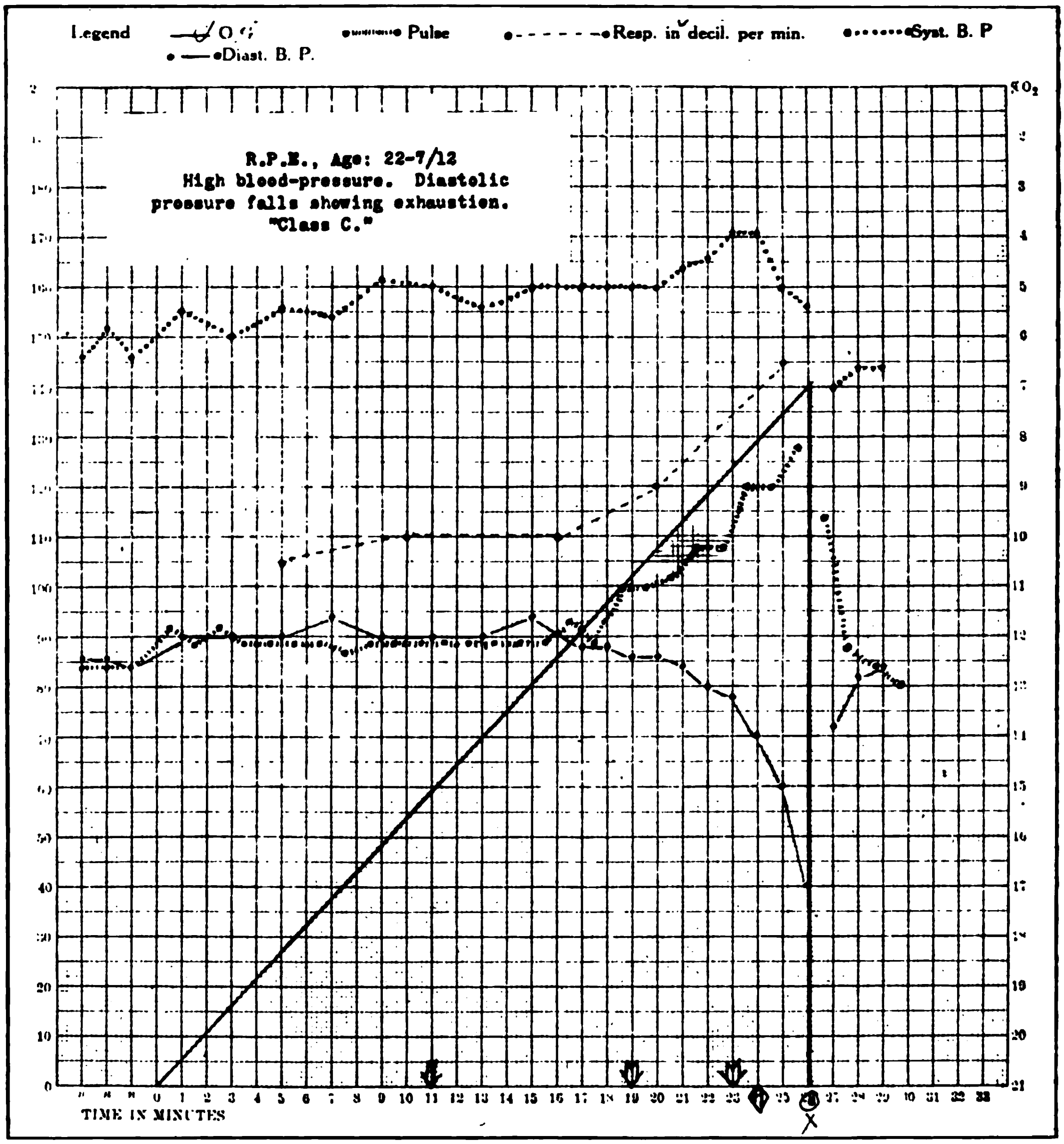
It is an old aphorism that age means only the condition of the arteries. It is well recognized abroad that the best age for the aviator is in the early twenties, and that the older he is beyond this point the less efficient he is likely to be in service. Our observations with the low-oxygen tests bear out this strongly and suggest that the explanation may lie in slight changes in the arterial walls and musculature at a much earlier age than it has been supposed that such changes can occur.

This statement does not imply that there are no men above 30 or even in their forties who belong to the "optimum" class, but the older a man is beyond 20 the more likely he is to show the arterial type of reaction to low oxygen. Thus, many men of about 35 will show a certain hypertension from the start, with a constant rise as the test goes on, e. g., 135, rising to 150 to 160. In these cases the heart muscle will carry the burden much longer than in the manifest arteriosclerotics, and there will be normal psychological reactions achieved by heart strain, followed eventually, in many cases, by dilatation of the heart.

ARRHYTHMIA.

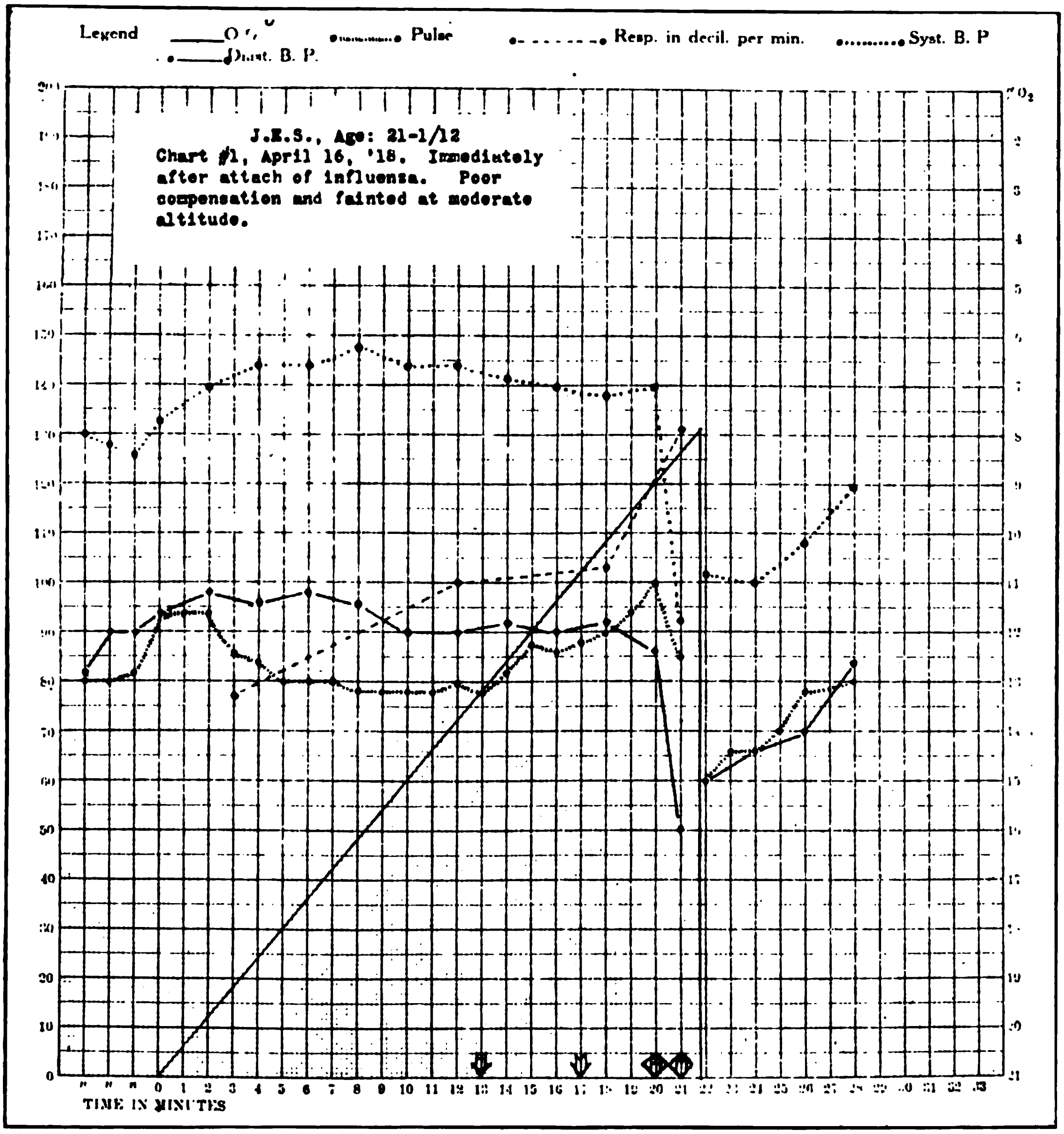
The effect of low oxygen on subjects who have any tendency to arrhythmia is very striking. Abnormalities of the heart-beat mechanism invariably become exaggerated to an alarming degree. An occasional extrasystole, for example, will occur more and more frequently as the test progresses, until the majority of the contractions are of ectopic origin or until there are considerable periods of abnormal beats in series like those of paroxysmal tachycardia. This, of course, interferes with the efficiency of the circulation, so that these subjects become very cyanotic, very uncomfortable, and fail early to perform well on the psychological tests.


Pulse
Resp. in deal. per min.
Syst. B. P
R.S., Age: 35-11/12
Type of case common at subject's age. Good compensation but high blood-pressure. No sign of exhaustion to a very high altitude, but will not wear well in service. "Class B"
CO_2
TIME IN MINUTES

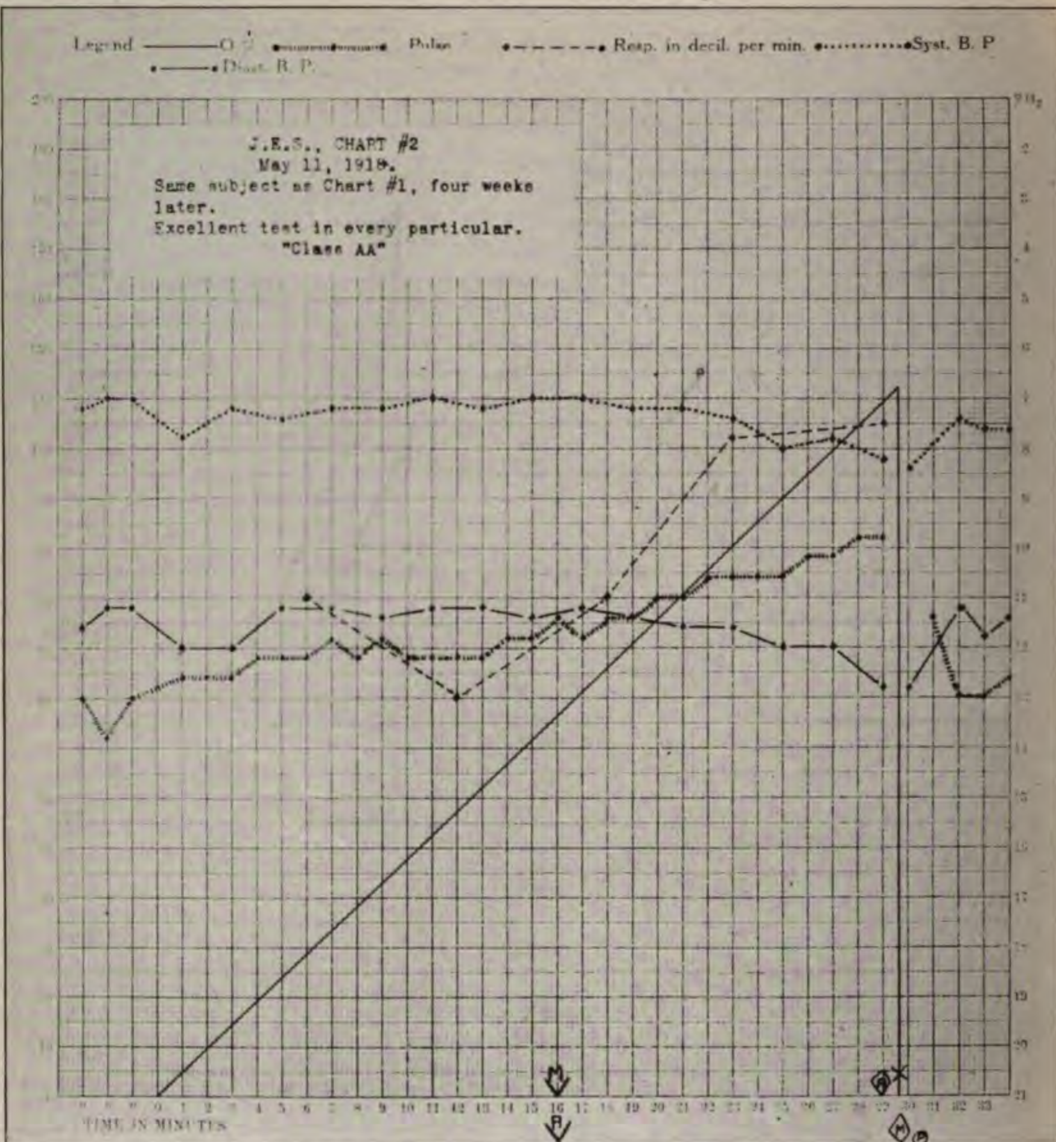


No. 325. CADET. Age 22 years, 7 months.

This chart shows compensation. There is a fair response in respiration. There is a typical rise in pulse and systolic pressure and a controlled but rather rapid terminal fall of the diastolic pressure. The systolic pressure is too high for an A rating.



Legend
Pulse
Resp. in decil. per min.
Syst. B. P
Diast. B. P.
J.E.S., Age: 21-1/12
Chart #1, April 16, '18. Immediately after attach of influensa. Poor compensation and fainted at moderate altitude.
TIME IN MINUTES



No. 63. CADET. Age 21 years, 1 month.

Left the hospital three days ago where he was laid up for a week with influenza. Feeling fairly well to-day, though not up to his usual form.

The first chart (chart 1) is typical of a man out of condition, rather high systolic pressure, psychic rise in both pulse and pressure, followed by sudden faint at about 8 per cent. In this the diastolic pressure fell practically to zero; the systolic pressure and pulse also broke sharply as may be seen by the slow recovery after the experiment was terminated.

He was tested again two weeks later (chart not given) and made a very good run with the exception of a rather high blood pressure (148). In this test he was not completely inefficient when taken off at 5.5 per cent. After two weeks he was given a third test (chart 2), which entitles him to an AA rating. The systolic pressure stays below 140, there is no break in diastolic, and there is a moderate healthy rise in pulse.

This case illustrated the very serious effects of temporary indisposition.

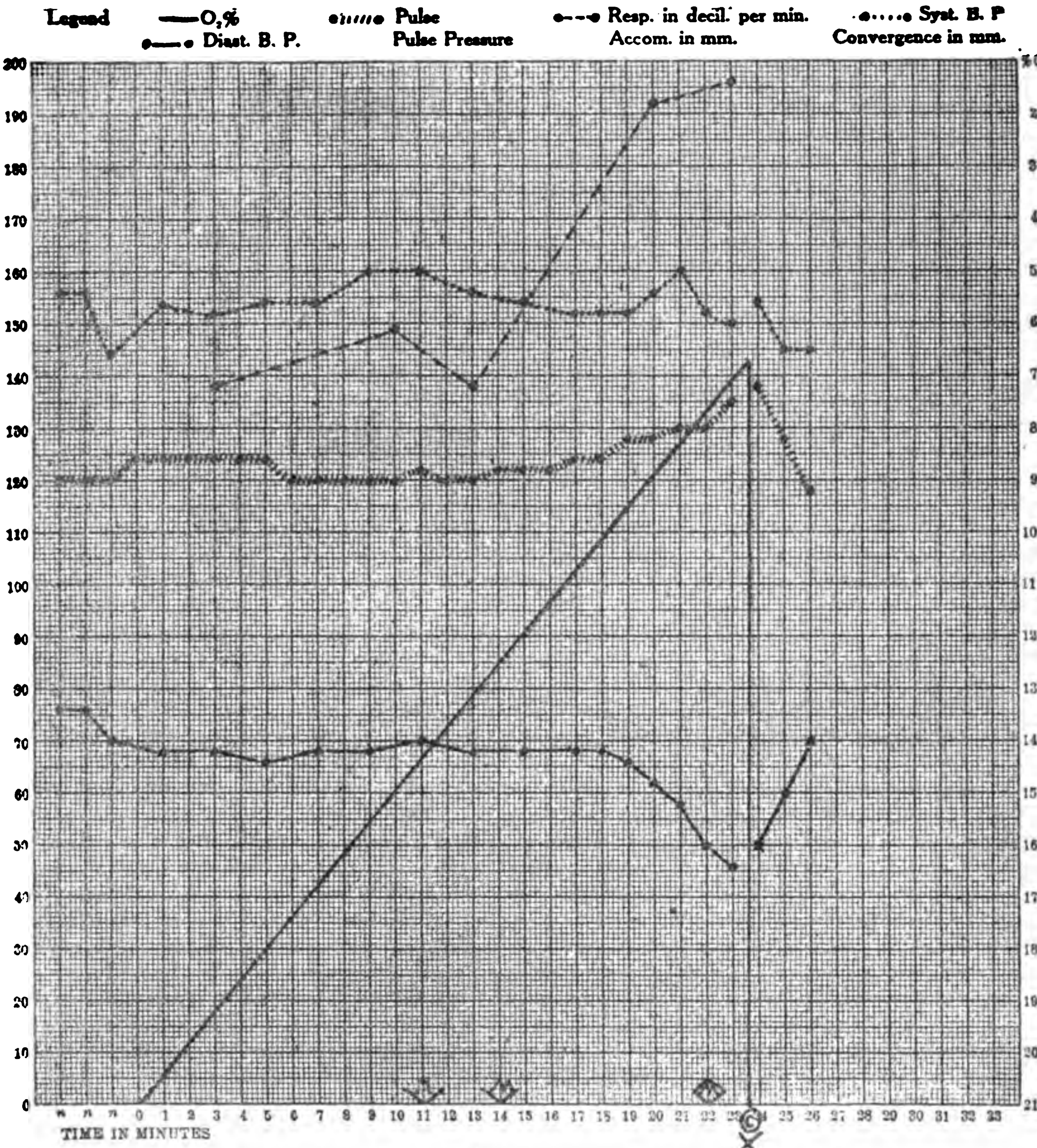


Chart 11.

No. 217.—D. R. **CADET.** **Age 20 years, 6 months.**

There was a roughening of the first heart sound heard before the test. No demonstrable enlargement, second sounds equal. During the test a definite systolic murmur developed and the pulmonic second sound was accentuated. There is no doubt of the diagnosis of mitral insufficiency well compensated.

The chart is typical of most cases of valvular lesions. The pulse is high throughout the test. The systolic pressure is high and uniform. Diastolic pressure begins to fall between 9 and 10 per cent, but is in control at all times. Respiration shows rather a marked response. Efficiency is well preserved, the psychological rate being A. This is accomplished at the expense of marked overwork of the heart. Although this is well borne at the present time, the presumption is that the subject would soon show the effects of wear, and permanent damage to the heart might easily result. Class D.

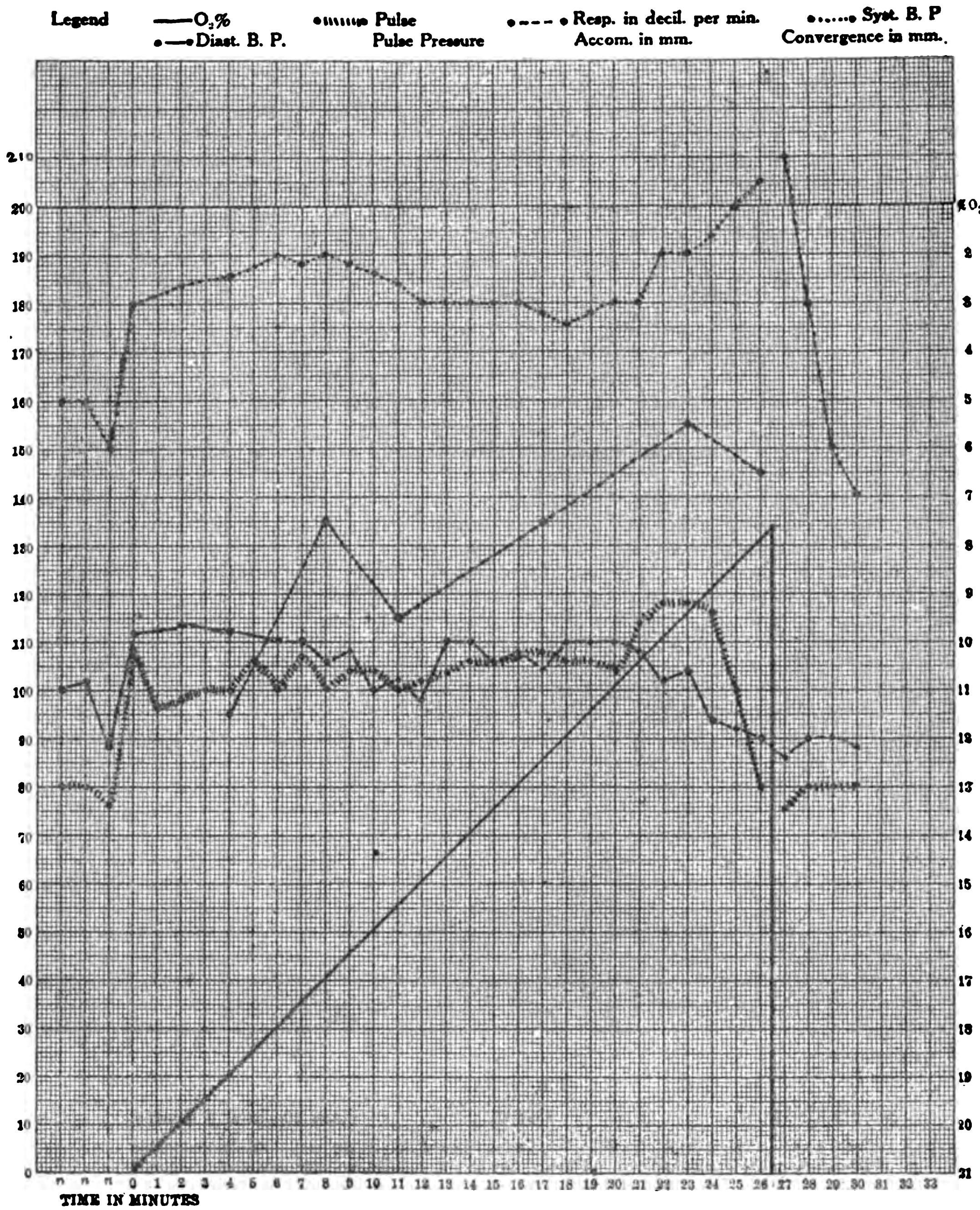


CHART 12.

No.—.—F.S.D. CADET. Age, 25 years 5 months.

An unusually bad record. Systolic pressure very high and at the end rises to 210. Diastolic shows marked fatigue though the oxygen percentage reached is not very low. Pulse rather high at the start shows very little acceleration later and at about 9 per cent begins to fall rapidly.

The heart sounds became roughened, suggesting a valvular lesion, which seems extremely likely from the blood pressure. Should be studied further; test should be repeated. On the showing of the chart given the rating should not be better than D.

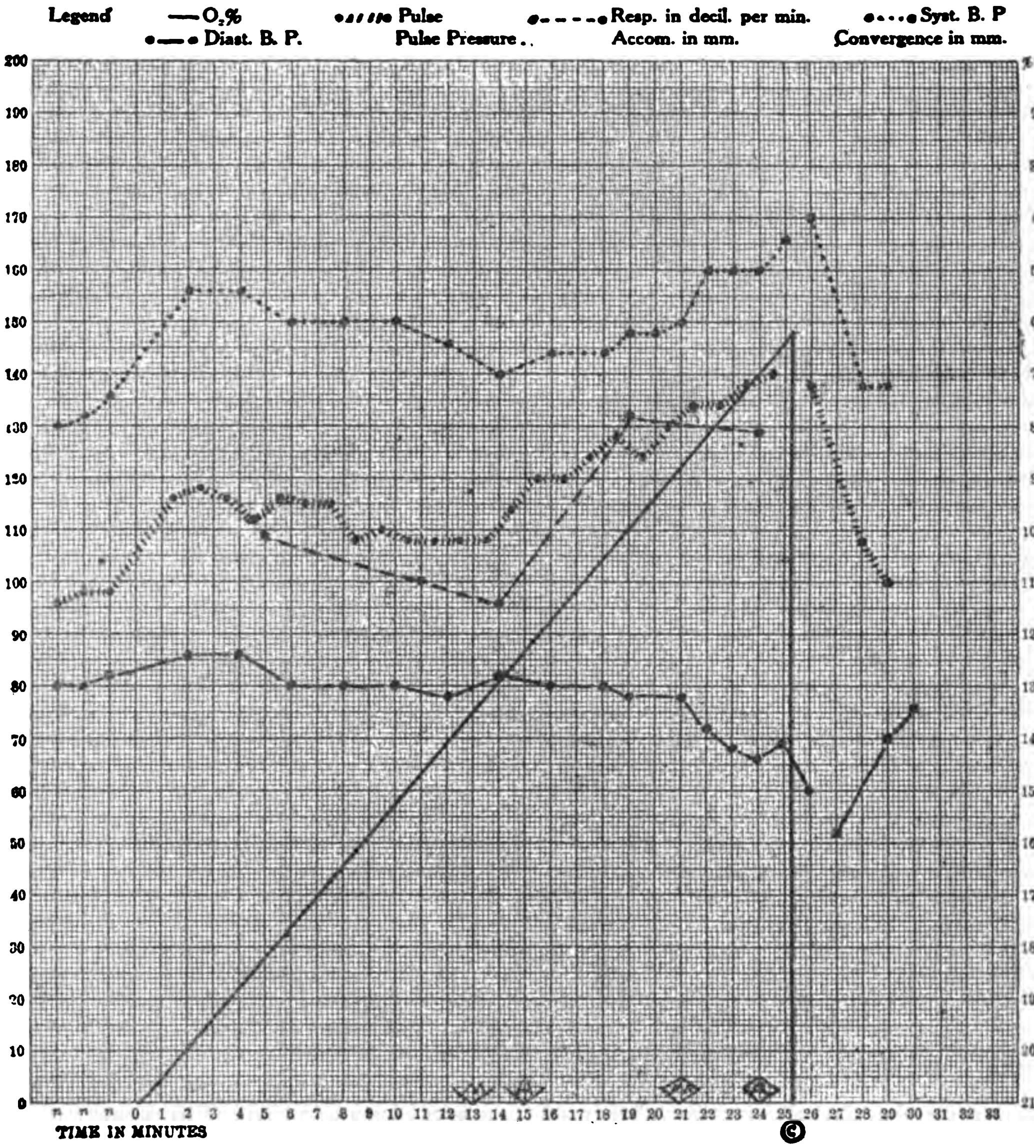


CHART 13.

No. 163.—H. B. R. CADET. Age, 23 years 5 months.

An example of compensation held to a very low percentage with heavy circulatory strain. There is a marked psychic reaction in both pressure and pulse at the start, but this subsides somewhat in the first 15 minutes and should not count too much against the subject. What is against him is the marked rise in pressure toward the end (166) together with a high pulse and falling diastolic, which may be interpreted as showing fatigue though no actual collapse occurred. Class C. Holds his efficiency well but at the expense of severe heart strain; high blood pressure and pulse. Nervous type. Would wear out rapidly if used for high work.

At the same time it may be remarked that these very qualities might make him a very valuable pursuit flier as long as he lasted.

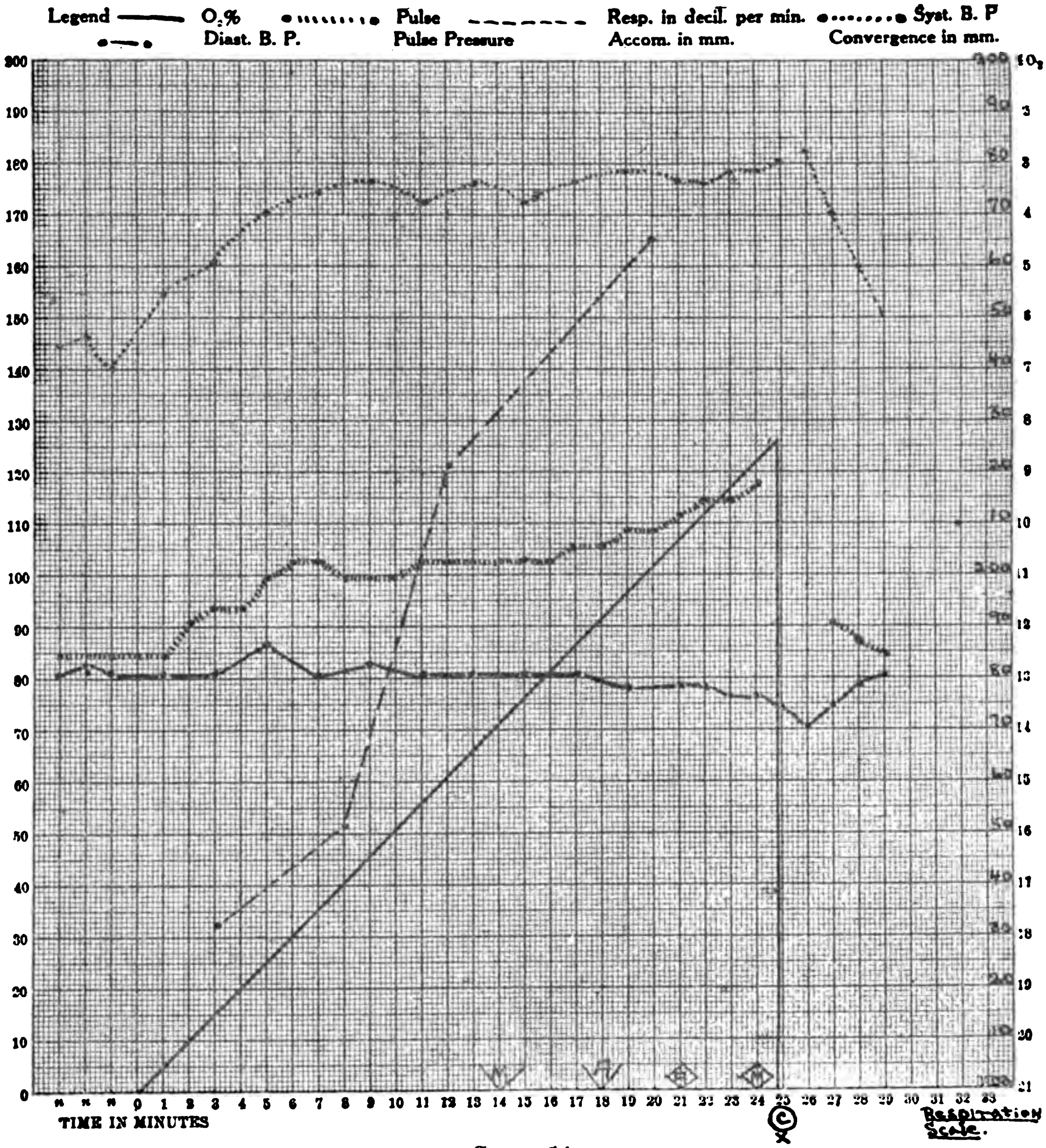


CHART 14.

No. 123.—W. B. R. CANDIDATE. Age, 23 years 2 months.

Suggestion of presystolic thrill and murmur at apex found before the test.

During test these became much more marked and a systolic murmur developed. Systolic pressure high from the start and steadily increased. Diastolic remained low. Note the very marked early increase in respiration indicating great discomfort in breathing. Became inefficient at a rather high oxygen percentage. This chart is characteristic of the way many valvular heart cases respond to the test. He was not carried far enough to get the circulatory collapse that would almost certainly have come as a result of the high pressure and pulse. Class B.

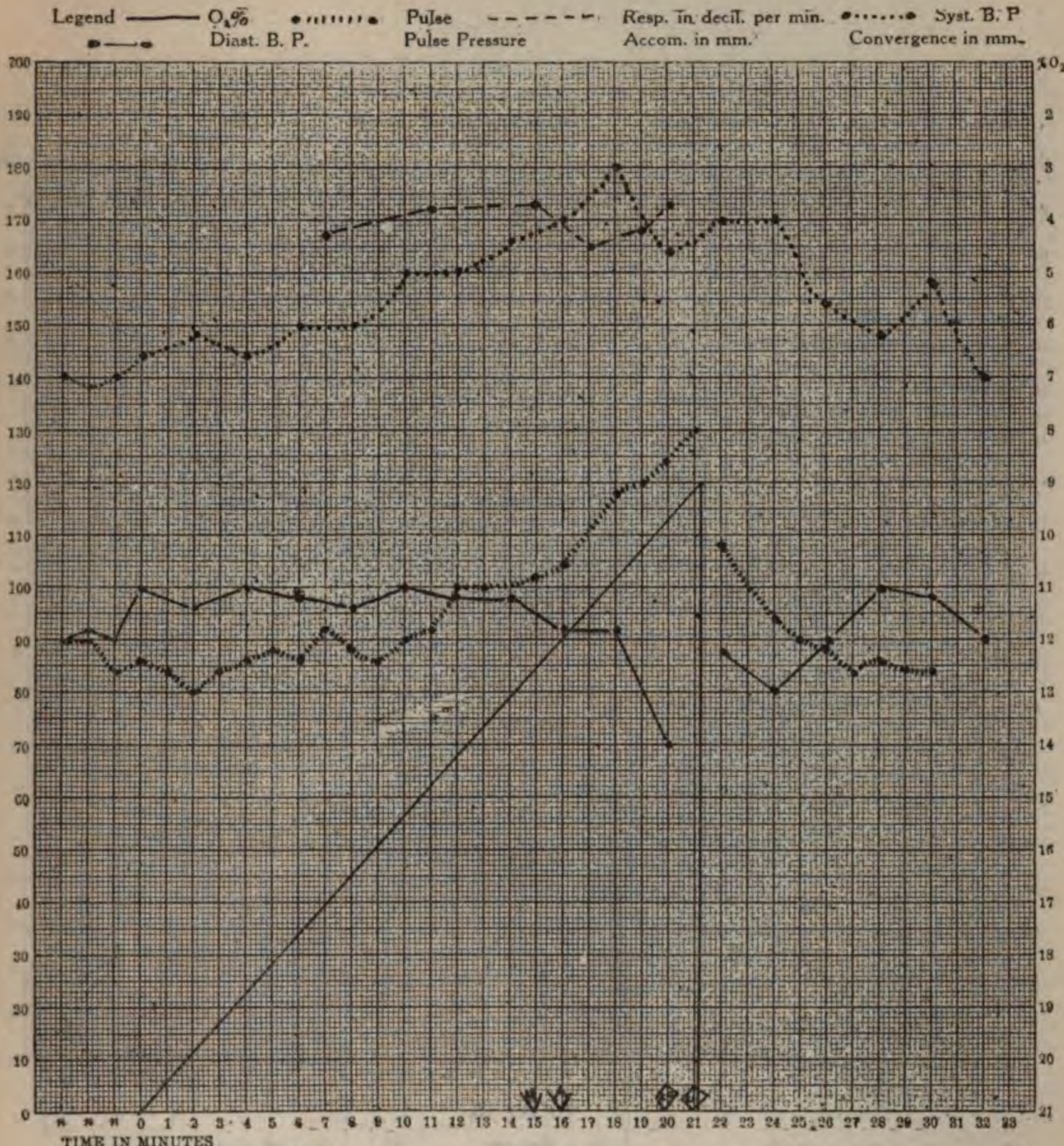


CHART 15.

No. 82.—D. H. O. CADET. Age, 24 years 7 months.

Only significant finding in history or physical examination was a rather red throat. Blood pressure reclining 120, standing 132, after exercise 146 and two minutes later 138. Was rather nervous on test.

Pulse reacts normally but rather excessively considering the percentage reached. Respiration somewhat full from the start, but shows no increase. Systolic pressure high and steadily increases to 180. At this point (above 10 per cent) the combination of high pressure and pulse seems to be more than the heart can stand. There was probably a dilatation; at any rate the subject almost fainted as indicated by the fall in both systolic and diastolic pressures. A very bad run, hardly sufficient to rate C. The test was repeated a week later. At this time the percentage reached was much lower before inefficiency. The blood pressure was still a little too high; 134 rising to 156. On the second run alone he would be entitled to B, but since he had shown high blood pressure twice, very high once, it was considered safer to rate him C.

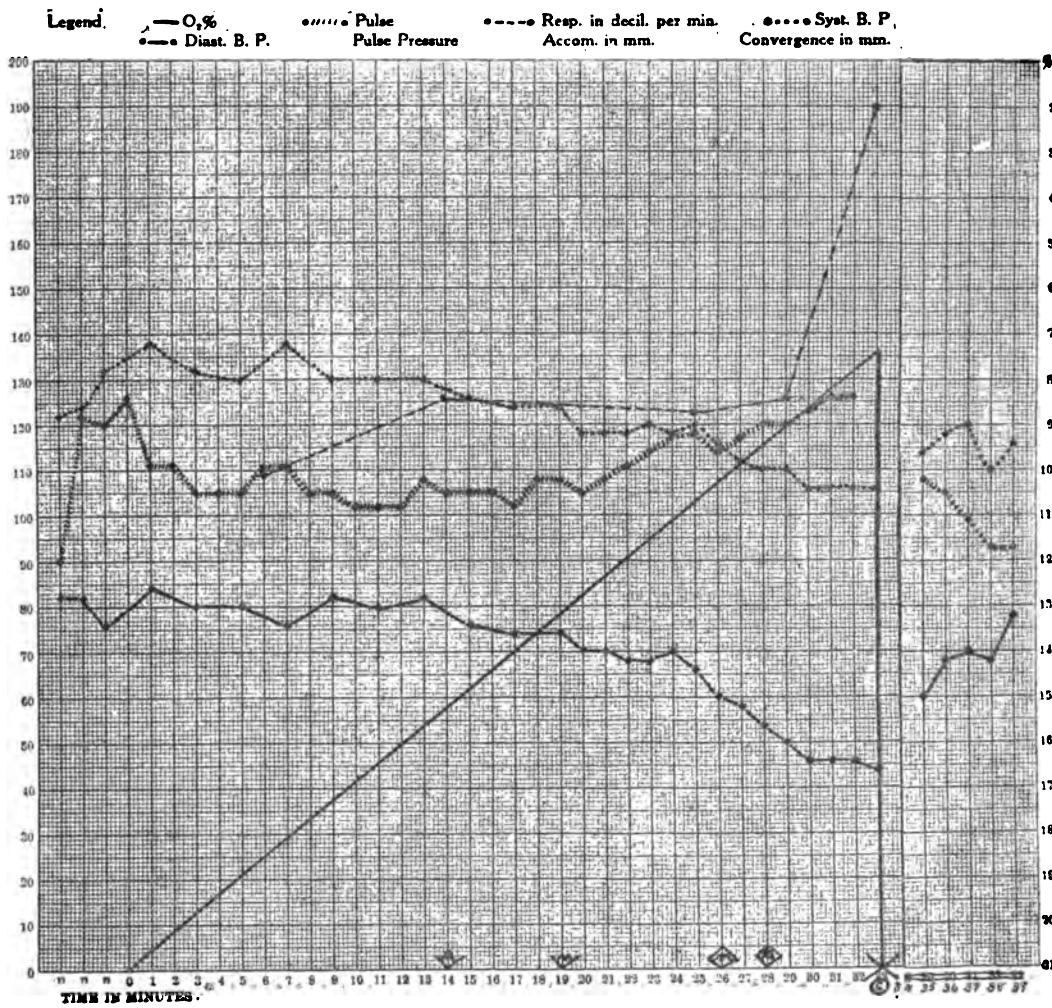


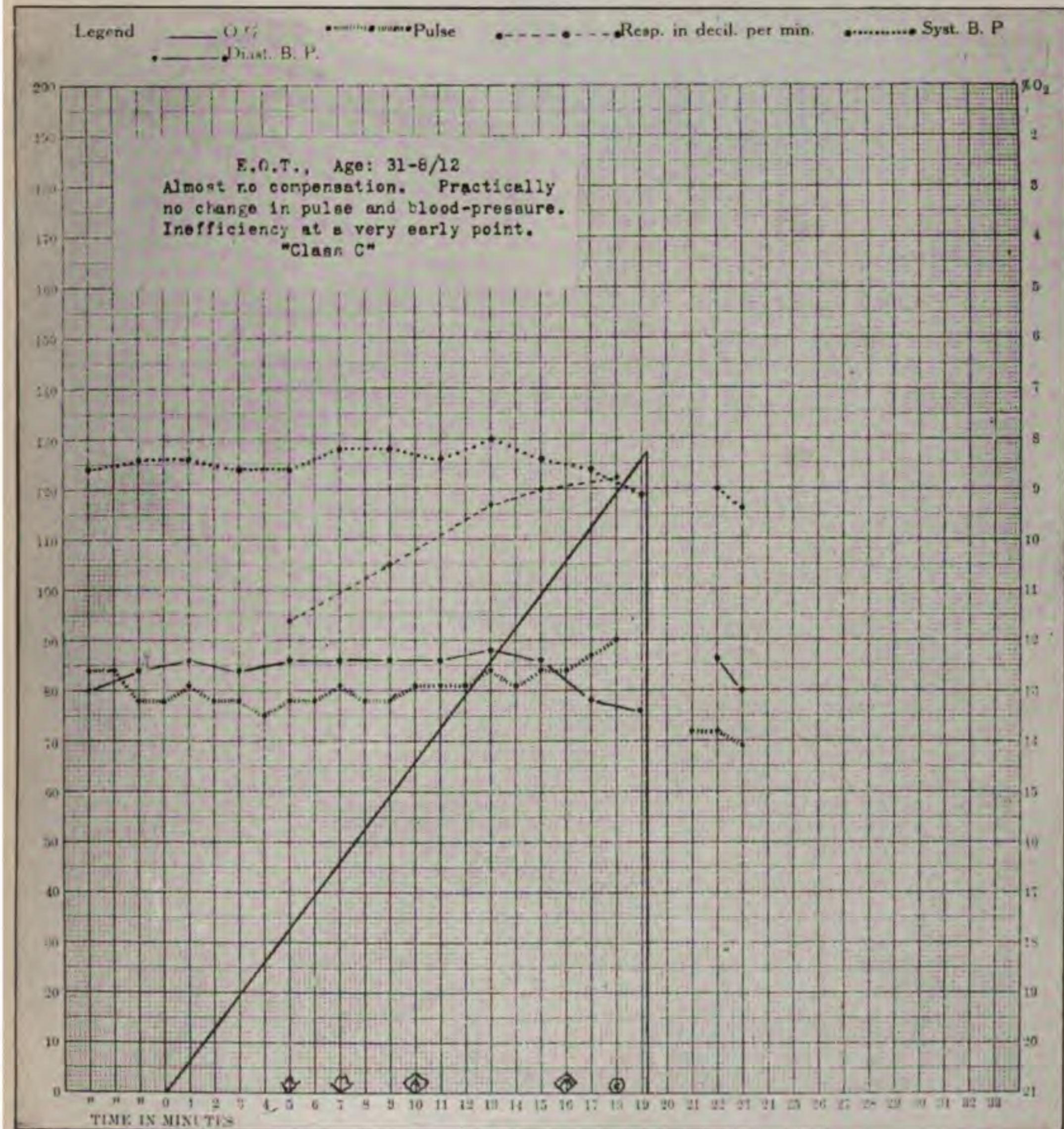
CHART 16.

No. 382.—A. M. G. PILOT. Age 25 years, 2 months.

This man is an instructor in flying and has had 200 hours of aviation. He feels decidedly stale and has asked to be relieved of flying for the present. Is afraid to go up because he has such poor judgment in his present condition.

Preliminary pulse: Reclining 69, standing 105; after exercise 120, two minutes later 102.

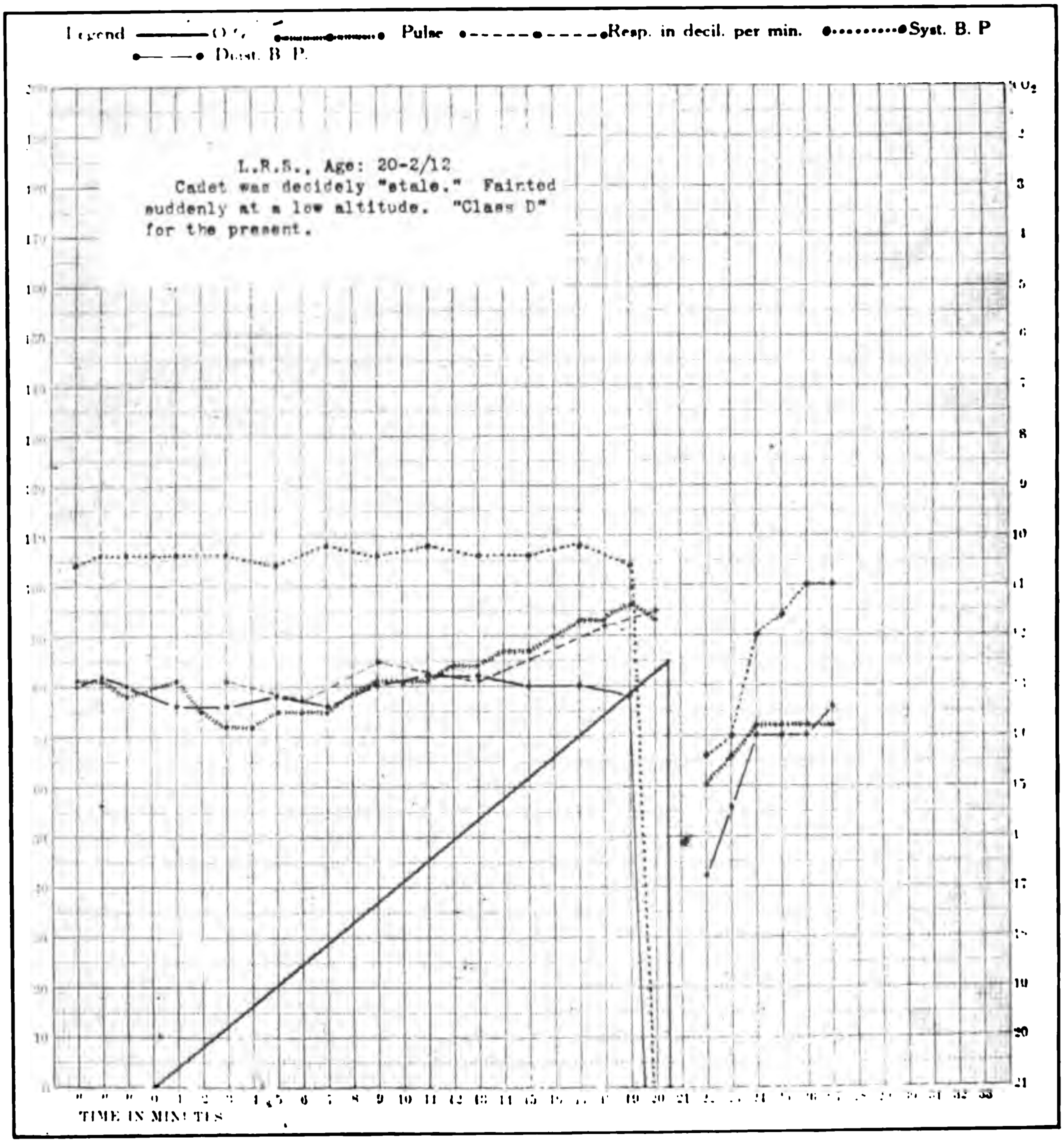
The only abnormal feature of his test was the slow but steady decrease in both systolic and diastolic pressures. He reached a fairly low oxygen percentage before becoming inefficient. The proof of staleness here is not full, but the preliminary pulse reactions and the blood pressures during the test are suggestive.



No. 50. PILOT. Age 31 years, 8 months.

In good health, but "out of training," and 20 pounds overweight.

This chart shows almost total failure to compensate. There is very little change in pulse or blood pressure, and the respiratory reaction is deficient. For this reason there is early appearance of inefficiency as shown by the psychological characters, and he is "completely inefficient" above 9 per cent. Since there is no circulatory reaction there is no evidence of strain. Class C. Because inefficient at a relatively low altitude.



No. 144. CADET. Age 20 years, 2 months.

Is decidedly "stale," hates to go up in the air at all. Feels tired and depressed and is discontented in the service at present. Certain complications at home are on his mind a good deal.

This chart is typical of a man in poor physical and mental condition. He fainted rather suddenly at about 13 per cent. Previous to this he had shown little compensatory response, blood pressure too low from the start, pulse rising slightly and respiration hardly at all affected. This man might be expected to faint at any time during a flight irrespective of elevation.

No rating given but for the time being is unfit to fly at all. Withdrawn from flying and recommendation made for furlough.

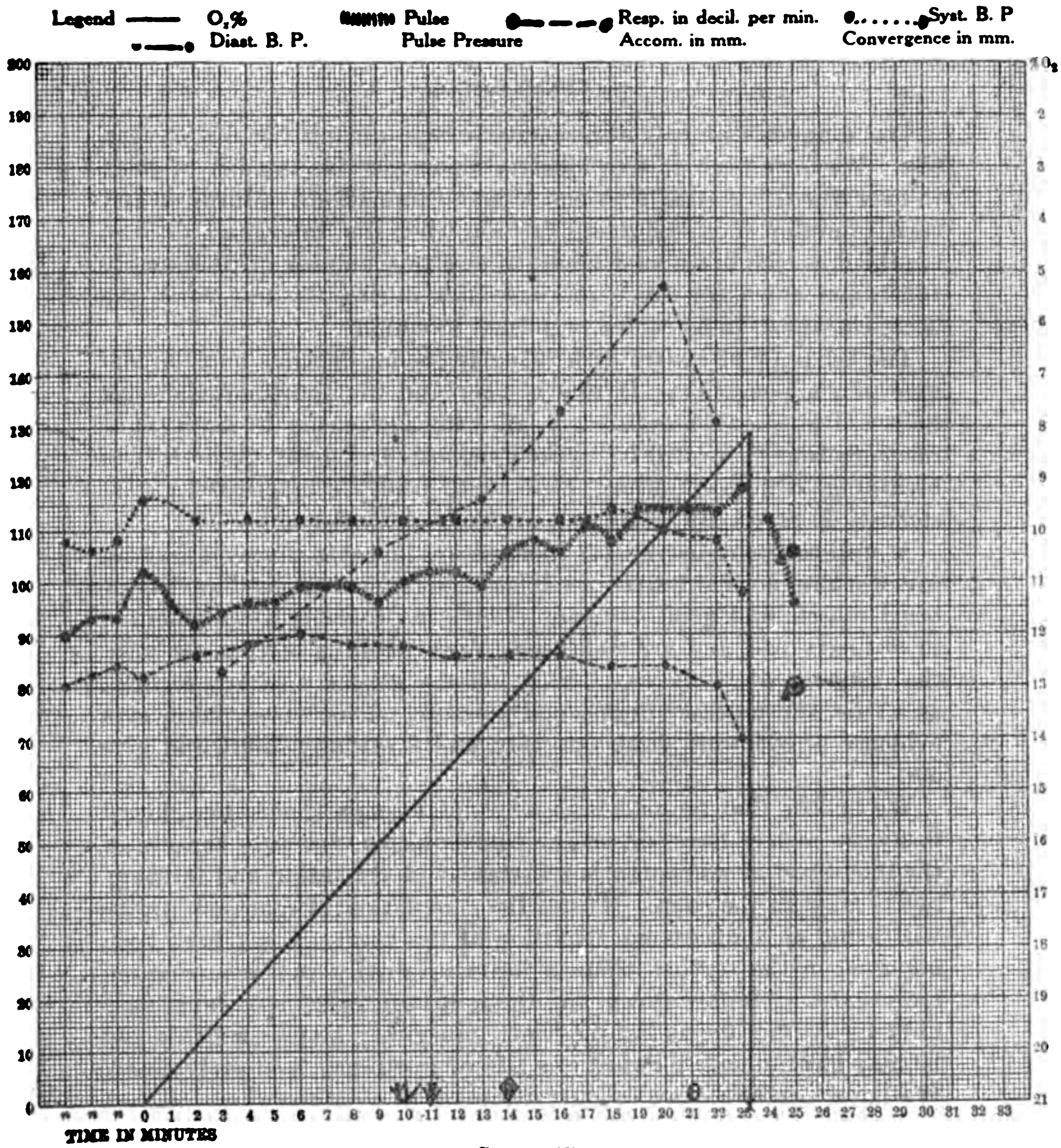


CHART 17.

No. 51.—R. N. H. PILOT. Age 23 years, 6 months.

This is another example of poor compensation. Very little response in pulse, none in systolic pressure, very low pulse pressure. Respiration increased but later feel off. At the end there is a fall in systolic and diastolic pressures indicating failure of the circulatory apparatus to continue even the limited effort it is making. Psychological effects early. Class C. Becomes inefficient at a relatively low altitude.

Sinus arrhythmia always becomes more marked during the test, but is to be regarded rather as a sign of youth and vigorous reactions than as an abnormality. It has no clinical importance as far as we know.

VALVULAR DISEASE.

The diagnosis of valvular lesions is easy during the low-oxygen test. We have been able to identify a considerable number of cases in men who had passed rigorous Army examinations. Murmurs and thrills develop in a surprising fashion when due to organic disease. On the other hand, we have observed a certain number of presumably functional murmurs which did not alter during the test while the heart continued to be perfectly normal in action.

The behavior of hearts with valvular lesions depends on their degree of compensation. If this is poor and the heart muscle weak they will give up the fight early, allowing inefficiency to develop; at the same time there will be marked cyanosis and great discomfort in breathing, with palpitation. Cases with poorly compensated mitral stenosis do especially badly and are very uncomfortable.

A well-compensated mitral inefficiency, however, behaves like an overworking normal heart. Such hearts must have a good quality of heart muscle and good coronary circulation to remain compensated in ordinary life, and are well used to overworking at times to meet the demands of every day. They react vigorously to low oxygen, as a rule, run a rather high blood pressure, an increased pulse, give evidence of overwork from the start, and eventually dilate and give out.

We believe that no man with a valvular lesion should be allowed to fly, no matter how perfect the compensation, not only because of the likelihood of immediate heart strain, with dilatation and fainting, but because in the course of time the cumulation of repeated strains will bring on a disastrous condition of the heart. Cases have been observed in the service where a heart originally well compensated has eventually broken down, and the subject in these cases is not only unfit for further flying but the heart injury may be irremediable and he may have to look forward to a life of invalidism and early death. We have seen two cases of mitral disease in aviators where distress was found to be pretty marked when the plane rises to 2,500 feet.

ATHLETIC HEARTS.

"Athletic hearts" behave particularly badly under low oxygen. There is still no general agreement as to just what this term signifies, whether it represents merely a great hypertrophy of the heart which has not receded or whether there has been definite injury to

the heart muscle by strain. The latter supposition is the more probable, because we know that the normal body not only possesses great powers of increasing its various functions to meet special calls, but that the recession from such unusual increase in tissue and function is normally accomplished easily and safely. We must, therefore, assume on general principles that the so-called "athletic heart" means an injured heart muscle, not a subinvolution. Clinically the diagnosis is usually easy: A history of excessive athletics, especially rowing and distance running, a heart somewhat enlarged to percussion, an abnormally heaving apex beat, and sounds which are either notably loud and booming, or in a later stage are of poor and valvular quality. There is usually an absence of murmurs, though the dilatation can easily lead to a relative mitral leak.

The reactions of the athletic heart to low oxygen are always excessive, marked increase in blood pressure and pulse, but there is likely to be a rather early loss of compensation, since the damaged heart muscle is unable to carry the strain; it will either give up the task (cyanosis, inefficiency, etc.) or will dilate and cause fainting.

IV.—MANUAL OF OTOLOGIC DEPARTMENT, MEDICAL RESEARCH LABORATORY.

1. Introductory.

MEDICAL PROBLEMS—OTOLOGIC RESEARCH PREVIOUS TO THE WAR.

Certain unique features concerning the study of the ear in aviation are worthy of special attention. Since our entrance into the war the Medical Department of the Aviation Service has encountered certain problems of ophthalmologic, cardio-vascular, respiratory, psychiatric, and other character. The work of research into the relation between the motion-perceiving function of the internal ear and flying, however, had been undertaken long before the entrance of the United States into the war. A group of otologists had conducted experiments and carried on investigations involving the end-organs, nerve paths, and brain connections of the vestibular portion of the internal ear for a period covering the preceding decade. Many months before the United States entered into the conflict several of this group of otologists had been in correspondence with the Medical Department of the United States Army upon the subject of the physical requirements of applicants for the air fighting forces, and the total available work done upon both sides of the Atlantic was made the basis of the standards adopted for these physical requirements of prospective Army fliers.

ARBITRARY REQUIREMENTS FIXED BY CHIEF SURGEON, AIR MEDICAL SERVICE.

Immediately after our entrance into the war the present Air Medical Service was organized. The Chief Surgeon of the Air Medical Service, when he was confronted with the problem of formulating a plan for selecting men for training as fliers for the Army, decided to attempt to limit the admissions into this service to men who were definitely known, as far as was possible to determine by skilled medical examinations, to be possessed of normal physical equipment.

ONLY PHYSICAL ITEMS COVERED BY MEDICAL EXAMINATION.

The determination of their possession of all attributes other than physical fell to another division of the Air Service, the Mental Examining Board, and at no time constituted a part of the work of the Medical Service. The sole duty of the Chief Surgeon with respect to the examination of applicants for flying training was to demonstrate in each man the presence of normal physical equipment.

FORMATION OF STANDARD BLANK FOR PHYSICAL EXAMINATION.

For the purpose of furnishing a standard plan on which these physical examinations could be conducted upon a uniform basis, blank 609, A. G. O., was formulated, after consultation with the highest medical authorities in the various special fields of medical work covering the complete physical examination of man. The ophthalmologist, the otologist, the rhinolaryngologist, the neurologist, the respiratory and cardiovascular specialist, the gastroenterologist, the orthopaedist, the general surgeon, the dermatologist, the genito-urinary specialist, are all represented in the constitution of this examination blank, and the general field of complete physical examination covered to the satisfaction of each.

PHYSICAL EXAMINING UNITS.

Special care was exercised to pick the highest grade medical examiners available at each point where it was deemed necessary to establish a Physical Examining Unit, and the work of each unit was departmentalized in the best manner possible to render each examiner capable of serving in his most efficient capacity.

No difficulty was encountered in securing the services of men well trained in all special medical work represented in this blank, with the notable exception of the examination of the internal ear. This was relatively so new that the limited number of those capable of doing this portion of the work rendered it necessary in establishing each Physical Examining Unit, to pay special attention to the selection of the otologist. In many instances it was necessary to develop

the man capable of handling this portion of the work by a special intensive course of training and instruction.

DETAILED INSTRUCTIONS.

Carefully detailed instructions were prepared by high authorities upon the individual medical branches involved in this special examination, and these were sent to each Physical Examining Unit for its guidance; from time to time additional instructions were issued by the Chief Surgeon for the purpose of further improving the examining service; special visits to Physical Examining Units were made from time to time with a view to maintaining this service at its highest efficiency, and frequent consultation of the best-informed medical authorities on the subjects involved were held, in attempts to omit nothing which might improve the quality of this work. Full reference was made to the accumulated experience of the Allies; and confidential and other reports from medical officers in England and France were thoroughly digested and used to shape up the service of the Chief Surgeon's examiners.

IMPORTANT SENSORY EQUIPMENT.

Among the applicant's sensory equipments which were deemed important to demonstrate as normal were visual perception, sound perception, deep sensibility (or muscle-joint-splanchnic or kinæsthetic sense), tactile sense, and motion perception; special examination of olfactory, taste, and certain other special senses, such as cold, heat, pain, pleasure, sexual, tickle, hunger, thirst, nausea, and others were not deemed of sufficient military importance to warrant special scrutiny.

COMPARISON OF GROUND AND AIR SERVICE CONDITIONS.—MOTOR COORDINATIONS.—BODILY ADJUSTMENTS.—IMPORTANCE OF SENSES TO MOTOR ACTS.

The difference between the man on the ground and the man in the air lies in the fact that the former can stand still, the latter can not. When the flier walks across the field to his plane, all his motor coordinations are concerned with maintaining the proper relation between his body and the element which is supporting its weight, the earth. When he straps himself in the seat before flight he practically straps wings to his body; thenceforth, until the end of his flight, every motor coordination is concerned with maintaining a proper relation with the new element which is supporting his weight, the air. The only means he possesses of adjusting his relation with the new weight-supporting element is the plane; while flying, all motor coordinations, whether carefully calculated or instinctively per-

formed, are concerned exclusively with controlling the plane. The promptness and efficiency with which motor coordinations are performed depend directly upon the acuteness of sensory perceptions.

MOTION INDISPENSABLE TO FLYING.—SPECIAL IMPORTANCE OF MOTION SENSING.—INTEGRAL ELEMENTS IN MOTION SENSING.

Rising in the air in an aeroplane is made possible only by rapid motion. Acuity of motion perception assumes much greater importance to the flier than to the pedestrian, and in order to appreciate the full importance of this, one must have a clear conception of the component senses going to make up motion perception. Muscle-and-joint sense, splanchnic, visceral sense, kinæsthetic sense—all grouped for convenience under the term "deep sensibility," vestibular sense, vision and tactile sense, each participate in the composite of general motion perception.

DEEP SENSIBILITY ON THE GROUND COMPARED WITH IN AIRPLANE.

The motion sensing of deep sensibility on the ground is practically exclusively concerned with sensing the effect of the pull of gravity upon the body; in the air it is also concerned with sensing the effect upon the body of two other pulls, that of the plane's propeller and that of centrifugal force on curves. Impulses generated by these three pulls coming in via the deep sensibility tract must undergo accurate analysis in the brain and be properly estimated and labeled, if confusion and misinterpretation are to be avoided. While such analysis is accomplished by normal individuals, it is only at the expense of a certain amount of the more accurate sensing of the pull of gravity. Whereas on the ground practically 100 per cent of this incoming information expresses gravity pull, a less percentage of gravity pull is expressed by it in the air.

VISION ON THE GROUND COMPARED WITH IN THE AIR.

Vision, possibly the most important of all motion-perceiving senses on the ground, suffers some impairment of its usefulness in the air by reason of the reduction in the number of visible elements in the new environment, such as the usual objects making up the landscape. When darkness or cloud further reduces the utility of vision, this sense becomes almost eliminated as a source of guiding information to the flier.

TACTILE SENSE RELATIVELY UNIMPORTANT.

Tactile sense contributes less than any of the other three senses to motion perception on the ground; to the flier, although insulated by warm clothing, goggles, gauntlets, and helmet, it is still of value as a source of guiding information.

VESTIBULAR SENSE, ITS MOTION SENSING UTILITY AS GREAT IN THE AIR AS ON THE GROUND.

Vestibular sense suffers no depreciation in utility in the air as compared with on the ground. Its sole function has always been, and continues unaltered in any way to be, pure sensing of motion. In flying, therefore, its function assumes a relatively greater importance than that of the other special senses cooperating with it to furnish the individual with his composite of knowledge concerning motion.

In view of the foregoing, it is apparent that, in flying, motion takes on a much greater importance as regards potential safety or disaster for the individual than it possesses on the ground and that motion perception is commensurately of greater importance in the air than on the ground.

Regardless of the actual percentages which would express the shares of vision, deep sensibility, vestibular and tactile sense in the total of motion-sensing on the ground, it is established that three of these four are reduced in efficiency by conditions incidental to flying, and the fourth, vestibular sense, is not so reduced, and is therefore of relatively increased importance. It follows that it is of prime importance to determine that men to be trained as fliers possess normal vestibular apparatus. So important is it for the flier to possess normal vestibular acuity of motion-perception that no man should be permitted to begin training as a pilot who has not definitely shown normal reactions to vestibular tests.

VESTIBULAR FUNCTION STANDARD REQUIREMENTS.

The entire vestibular apparatus was tested as carefully and as accurately as the state of our knowledge concerning it permitted. It was decided to reject applicants whose vestibular apparatus gave evidence of motion-sensing acuity below a certain degree, albeit it was fully realized, in establishing this limit, that it in no way represented a line of demarkation between acuities of this perception compatible with and incompatible with flying.

POSSIBILITIES OF GREATER LATITUDE REALIZED.

It was fully realized by the Chief Surgeon and his staff that it is possible for a man to fly with a vision of 20/40 or 20/60, or with a talipes, or with a hearing of 5/40. The decision was arbitrarily made, however, that no man would be accepted for flying training by the Army except those with 20/20 vision, absence of gross malformations, 40/40 hearing, and acuity of vestibular motion-perception as represented by a minimum of 16 seconds' nystagmus and normal past-pointing and falling responses to standard stimulation.

DIFFICULTIES IN DECIDING UPON ARBITRARY STANDARDS—CONFIRMATION OF WISDOM OF ADOPTED STANDARDS.

At the time of the establishment of these standards it was recognized as a very difficult matter to state dogmatically what constituted the average length of nystagmus and past-pointing. All that could be relied upon were deductions from clinical experiments with a series of healthy individuals examined by various observers over a period covering over 10 years as contrasted with the impaired responses observed in over a thousand pathologic cases. It was realized that it was a great responsibility to establish what should be regarded as normal responses. It is therefore with a great deal of satisfaction that we publish at this point the composite results of the turning-chair test performed by skilled standardized otologists in the examining units on many tens of thousands of applicants for the Aviation Service. A compilation of statistics has been made, the digest of which, with respect to responses in nystagmus, past-pointing and falling, entirely confirms the judgment upon which the original standards were based.

The turning-chair tests proper, exclusive of the static and dynamic tests, are cause for practically all of the rejections in this particular field, being 2 per cent out of a total of 2.04 per cent, or 2 out of every 100 men examined. The average duration of nystagmus of the entire number of men examined was, after turning to the right, 23.5 seconds; after turning to the left, 23.2 seconds. In those who qualified, the nystagmus, after turning to the right was 23 seconds, after turning to the left, 23.1 seconds.

The average number of past-pointings for the total number examined is as follows:

After turning to right with right arm	3.8 times
After turning to right with left arm	3.7 times
After turning to left with right arm	3.8 times
After turning to left with left arm	3.7 times

POSSIBILITY OF ALTERATION IN ADOPTED STANDARDS.

The Chief Surgeon held himself in readiness to alter the adopted physical standards at any time evidence indicating the wisdom of so doing was adduced; realizing the wealth of available material for Army fliers at the start of the formation of the United States Flying Corps, it was deemed best to maintain the highest standards until it became apparent that a change was for the best interests of the service.

FALLIBILITY OF ENTRANCE EXAMINING SERVICE.

The physical examinations of applicants were carried out at 67 Physical Examining Units, 32 of which were constituted by Army

medical men in various camps. As was to be expected, a certain amount of evidence of the fallibility of these examinations has come to light. Certain men have been encountered in the Air Service who were physically unfit, and certain others have been rejected who were physically fit. Considering the magnitude of the task, however, a review of the results of the examinations of a hundred thousand applicants in nine months reveals a performance on the part of these examining units which is satisfactory to the Chief Surgeon.

2. Ear, Nose and Throat Requirements.

DETAILS REGARDING EXAMINATION OF QUESTIONS OF BLANK 609, A. G. O., FROM 13 TO 21, NOT INCLUDING 20, WHICH HAS ALREADY BEEN TOUCHED UPON.

13. *History of ear trouble*—
    (*a*) Ever have ringing or buzzing in either ear, earache, discharge, or mastoiditis?
    (*b*) Ever have attacks of dizziness from any cause?
    (*c*) Ever been seasick? If so, how often and how long does it last?
    (*d*) Ever had a severe injury to head?

The answers to question 13 are merely designed in a general way to arrive at an indication of any previous ear trouble. It is to be taken into consideration that very few candidates are willing to admit the history of ear discharge or dizziness, and conclusions will have to be drawn from the examination of the drumhead and subsequent hearing and rotation tests.

It is the universal experience that all candidates deny that they have ever been seasick, thinking thereby to prove that they would be unaffected by the motion of an aeroplane. Answers to this question for that reason must be taken with considerable allowance. It is to be emphasized that it would be improbable for a person with perfectly normal ears not to become seasick upon his first exposure to a rough sea.

14b. *Appearance of membrana tympani.*—A perforation of the drumhead, unless transitory, is to be regarded as a cause for rejection. If the drumhead is excessively thin and scarred, even if the hearing is normal, the applicant should be rejected. Experience has shown that even in the low-pressure chamber of the laboratory perforations can easily occur in such drums by a rapid descent.

Pathological conditions of the internal ear disqualify. Acute or chronic disease of the middle ear disqualifies, except that reexamination after full recovery may be made the basis of subsequent acceptance. Moderately retracted drumhead, loss of light reflexes, thickened drum membrane, and chalk deposits do not disqualify pro-

vided the hearing is normal. The pathology of the drumhead is not an index of the hearing ability. No conclusions can be drawn without hearing tests.

15 to 18. *Nasopharynx.*—This region must be carefully examined. If defect can be removed by operation, this should be required prior to acceptance. If nonoperable or operation is refused, it is a cause for rejection.

The question as to what degree of deviation of the septum demands an operation is a difficult one to answer and must be left to the experience of the examiner. One thing must always be clearly borne in mind; aside from the straightening of an occlusive deviation for the purpose of giving the candidate better air, resecting the septum is not infrequently of great value as a prophylactic measure. The majority of individuals who have trouble with their ears are troubled because of a postnasal and Eustachian tube catarrh. Septal deviation far back, impinging on the inferior turbinate and acting as a continual irritant to the nasopharynx, should be corrected. Cases of marked deviation which have led to atrophic condition of the mucus membranes do not necessarily require operations. The prime object is to prevent acute postnasal trouble which might come on as a result of exposure, rather than to attempt to obviate an insidious middle-ear catarrh which might have come on in later life.

The nares should be most carefully examined for any signs of accessory sinus diseases. Even a suspicion of this condition should lead to a most careful and painstaking examination, including properly taken X-ray stereoscopic photographs.

16. *Condition of tonsils and history of attacks of tonsillitis.*—The diagnosis of diseased tonsils is a difficult one and must be left largely to the experience of the individual examiner. Candidates are disinclined to admit a history of sore throats. It must not be forgotten that probably 80 per cent of the sick calls on the other side is made up of sore throats. Soldiers who never complain of throat trouble in this country when they are subjected to the exposures incidental to field service rapidly develop inflammatory throat conditions, which disqualify temporarily for duty. One should be cautious in declaring a tonsil healthy. All throats should be examined under good illumination; attempt to express contents of crypts should be made, and if questionable matter can be squeezed out the tonsils should be removed. Buried tonsils in which the anterior pillar is affected should be removed, as should the hypertrophic type. The experience in this laboratory has been that in spite of the fact that all candidates were originally examined by throat specialists, many when reexamined in this institution showed diseased tonsils. Our general impression is that it is better to err slightly on the side of radicalism in regard to operation on the tonsils for those about to enter active military service.

Examination of the teeth must not be neglected. It must never be forgotten that crowned teeth, pyorrhea, and alveolar infections may be the sources of much toxemia. Special attention should be given to this matter, and if there is any doubt in the mind of the examiner as to the condition of the candidate's teeth he should be instructed to have his mouth put in good shape before finally passing him.

17. Adenoid tissue is very common in children and increases in size from birth to the age of 6 years and then normally subsides about the age of puberty. One does not expect to find much adenoid tissue in adults. Adenoids do their harm early in life, and this, as far as it concerns this examination, is evidenced by deformed jaws, misshapen noses, and poor hearing. Adenoid tissue in the adult is easily seen with a post-nasal mirror, the digital examination being unnecessary.

18. The condition of the Eustachian tubes is one of vital importance. Generally speaking, it can be said that if the candidate's drumhead and hearing are normal the Eustachian tube is probably in good condition. In addition, regulations require that the patulence of the tube should be demonstrated by the auscultation tube during inflation by means of Politzerization or catheterization. The former procedure is ample for all practical purposes. If tubal troubles are of such a nature as to demand it, an examination should be made with some good pharyngoscope.

STIMULATION OF END-ORGANS.—RESULTS SENSORY, MOTOR.—VERTIGO.—KIND OF MOTION USED AS STIMULUS.

20. *Vestibular tests.*—The motion-perceiving apparatus of the internal ear is subjected to stimulation by motion of certain standard quantity and quality, and the results are observed according to uniform standard methods. Two results are noted—a sensory result, the subjective sensation of motion, and a motor result, involuntary movement of the eyes. When the subjective sensation of motion is in accord with fact, we call it normal sensing of motion; when it is not in accord with fact, we call it "vertigo." The only difference between normal perception and vertigo lies in the sensing of motion being in accord with or contrary to fact. The most practical means of applying motion stimulus is by the rotating chair, inasmuch as the application of motion in a linear direction, for the period of time, and in the intensity necessary to elicit certain standard responses to that stimulus would necessitate apparatus entirely too bulky to be susceptible of practical application under ordinary conditions of office examination. By making use of a rotational-motion stimulus instead of a linear-motion stimulus it was possible to work out a standard means of applying motion stimulus in certain definite quality and quantity in a manner and by means of an apparatus easily handled in an office. For this reason only the subject of the tests of

the vestibular apparatus is made to experience rotational vertigo. An additional advantage in using the rotating chair is that it applies motion stimulus of a character to produce a more enduring stimulation of the end-organs of the semicircular canals.

Motion in a linear direction applied to a fluid contained in a closed semicircular canal is physically incapable of setting up a flow of that fluid, just as rotational motion applied to a fluid contained in a straight canal can not set up a flow.

NYSTAGMUS.

Ewald's experiment long ago determined that involuntary pulling of the eyes in a certain definite direction and plane occurs during the time the fluid in a normal semicircular canal is made to flow in one direction; and during the time this fluid is made to flow in the opposite direction involuntary pulling of the eyes in the opposite direction occurs. By applying rotational motion it is possible to reproduce Ewald's experiment in effect, as a test of eye reactions to vestibular stimulation; and when the character and intensity of rotational stimulus is standardized, comparisons of the results can be made and a normal eye reaction determined. This motor expression of motion stimulation is nystagmus.

MEASURING VERTIGO—VOLUNTARY TESTIMONY—INVOLUNTARY TESTIMONY—TECHNIQUE—POINTING TEST—STANDARD TECHNIQUE OF POINTING TESTS.

The normal man experiences a sensation of vertigo for between 15 and 40 seconds after being turned according to standard technique. Evidence of this subjective sensation may be had by voluntary or involuntary testimony; voluntary testimony, such as "I'm turning to the right," "I'm still turning to the right," etc., during the persistence of the subjective sensation; involuntary testimony, such as pointing test and falling. Standard tests make use of involuntary testimony in all cases; occasionally this is amplified by voluntary testimony with advantage. In observing the pointing before turning, a very important element in the test can be injected by implanting in the mind of the applicant the definite idea that he is to attempt to determine the location in space of the observer's finger solely by registering in his memory the location of it according to his tactile sense. This can be augmented by having him touch the observer's finger in more than one position, as, for instance, directly in front of the right hand, come back and touch; then locate again 30 degrees outward and come back and touch; the same procedure in front of the left hand. This implants in his mind the fundamental idea of being able to orientate himself solely by means of in-

formation coming from his tactile end-organs. After standard rotation to the right, for example, normal man experiences a certain very definite vertigo, a subjective sensation of turning to the left in the same plane as the rotation for a normal period of time. If the pointing test is carried out during this period of vertigo, instead of succeeding in pointing accurately to the testing finger he executes the pointing in accordance with his subjective sensation of motion. Feeling that he is turning definitely away from the testing finger to the left, for example, he reaches for it to the right. This is normal past-pointing.

INSULATION OF SUBJECT.

The insulation of the applicant during this test should be as perfect as possible. A black domino mask should be used, absolute quiet should be maintained, olfactory impressions should be shunted out, and he should be left as solely as possible dependent upon the information brought to him along the vestibular tract alone.

SIGNALING SUBJECT—OBVIATING SEARCH MOVEMENTS—OBSERVING PAST-POINTING—HOW TO CONSTRUE COMPENSATORY POINTING.

The applicant should be definitely instructed before turning that he should not expect a verbal order to touch the observer's finger, raise his hand and come back, and attempt to find it after the turning; he should be practiced before turning in executing his touch, raising his hand, and coming back to find the finger upon receipt of the signal from the observer's finger as it comes into the position which it maintains during the test—the observer bringing up his finger into position so as to tap the applicant's finger as a signal for him to execute his pointing without verbal command. It is very important for the applicant's finger to find a finger of the observer when he comes down in search of the finger which is testing him. Otherwise, there is injected into his mind a disconcerting element of dissatisfaction in having failed to find the finger for which he was searching. For this purpose the index finger of the observer's left hand can be held in readiness to furnish the touch necessary to shunt out this sense of failure. In observing the past-pointing after rotation, the observer's right index finger should be definitely fixed against the observer's hip so that visual attention to it on the part of the observer can be dispensed with, the hip rest insuring its remaining definitely where it was when the applicant first touched it in making the pointing test. The observer's eyes can be free to watch the applicant's finger at the top of the swing. Past-pointing at the top of the swing is just as definitely normal past-pointing as at the completion of return to touch. Many cases compensate after evincing a normal tendency, let us say, to past-point outward with the right hand when they should do so, and subsequently execute a compensa-

impairment of function of the vestibular apparatus in varying degrees ensues upon any such attack. It therefore becomes necessary to reexamine fliers at regular intervals in order to make certain that no functional deterioration of the vestibular apparatus has taken place. Regular examinations should be made at intervals of about eight weeks. Special examination should be made at once of any flier who manifests unusual failure to negotiate air maneuvers with ordinary skill.

3. Otologic Problems Under Consideration at the Medical Research Laboratory.

The first otologic problem attacked in the Medical Research Laboratory was the effect of low oxygen on the phenomena of nystagmus and past-pointing. It has been demonstrated by the cardiovascular and physiological departments that deleterious effects of low oxygen are noted in connection with the cardiovascular and respiratory systems. As was to be expected, before low-oxygen effects on the internal ear motion-sensing apparatus could be demonstrated, cardiovascular and respiratory effects became manifest. Therefore, it has thus far been difficult to carry these ear tests to a satisfactory conclusion. In these examinations the rotating chair was placed in the low-presure tank with the subject and observers. After having attained a height of 5,000 feet, the candidate was exposed to the effects of this altitude for 5 minutes, when the routine nystagmus and past-pointing experiments were carried out. The same procedure was repeated at varying altitudes up to 18,000 feet. These findings, reported in detail in another article, showed no consistent variations from the responses obtained at sea level. We may, therefore, with a fair degree of safety assume that at altitudes up to 18,000 feet no marked changes in this function of the internal ear occur as the result of low oxygen. The cochlear portion was similarly unaffected at these altitudes.

During these experiments abundant opportunity was afforded to examine a large number of drumheads—both of the candidates and of the observers. Experimental work in the laboratory has confirmed the practical observations of fliers—that middle-ear difficulties occur during descent rather than ascent. One point has been established without question, that the amount of injection of the drumhead is directly proportionate to the degree of patulence of the Eustachian tube. Intense pain in the middle ear and down the neck was experienced by many subjects, who showed on examination, to have moderate or severe congestion of the naso-pharynx. One case was extremely illuminating and shows that we must not conclude that because atrophic rhinitis is present, the tubes must necessarily be patulous. One of the examining medical officers had extremely

atrophic and badly retracted drumheads with scars from repeated suppurative attacks. A rapid descent produced a double bilateral perforation, the perforations evidently occurring on the sites of former perforations. A sharp stabbing pain was felt as the observer dropped rapidly from 14,000 to 1,000 feet, and an examination showed a bright red circle of tiny blood vessels surrounding the pinpoint perforations. The subsequent healing was uneventful.

One of the observers, who had a history of repeated attacks of suppurative otitis media in early childhood, developed a typical acute purulent otitis media after several ascents in the low-pressure chamber on three consecutive days.

One of the foremost otologic problems constantly before the chief of the Air Medical Service has been how much leeway can be safely allowed in standard tests of vestibular functions and acuity of perception. As has been mentioned before, all motor coordinations made by the flier during flight, whether carefully planned and consciously performed or instinctively and subconsciously executed, have only one ultimate expression, namely, the determining of his relations with respect to his environment and with respect to the new element which is supporting his weight, the air. Either instinctive action or carefully considered intentional action upon the part of the flier is determined entirely by information which is coming into his possession concerning his relations with his environment. This information can be had by him only through the activities of his special senses. But possession of normal perceptive end-organs, nerve paths, and brain connections does not constitute definite assurance that the individual will accomplish satisfactorily balance or orientation. Further, he may accomplish balance satisfactorily and still be completely disorientated; or he may be properly orientated and fail to accomplish balance properly. The two are independent functions of the mind, closely associated, but in no way functionally interdependent. On the other hand, lack of normal perceptive apparatus does constitute definite assurance that the individual will be physically less able to accomplish balance or orientation, or both, under certain circumstances under which these would be possible for the man in full possession of normal perceptive apparatus. There are certain circumstances under which balancing can be performed adequately even by the man who is possessed of less than full normal equipment. There is no doubt that man can accomplish a certain kind of flying blindfolded, or without functionating vestibular apparatus, or without normal deep sensibility. Hence this important air medical problem is to study the "peak load" requirements, the conditions of emergency and confusion which may be encountered unexpectedly in the air, and to attempt to estimate carefully the minimum perceptive equipment which would be ade-

quate under these conditions to enable the flier to negotiate such difficult and unusual phases of flying. There are certain temperaments, certain types of minds, certain intangibly different mental composites, which determine the inability of the individual to negotiate these critical points in flying, even though he be in full possession of his sensory perceptive facilities. "Self possession," "coolness," "bravery," "sand," "nerve," "presence of mind," "judgment," on the other hand, added to a perceptive equipment of less than normal may determine the success of an individual in emerging safely from a critical air situation. While this is unquestionably the fact, these mental qualities are so intangible, so indeterminable, and, above all, so distinctly not in the category of things physically to be examined and measured by the medical examiner that it is not deemed justifiable for the physical examiner to admit into the Air Service or to allow to remain in the Air Service anyone who is discovered to be lacking in acuity prescribed for the several special senses known to be prime requisites of the flier.

MOTION-SENSING EXPERIMENTS IN LINEAR UPWARD AND DOWNWARD DIRECTION.—GROUPS TESTED.—CONDITION OF TESTS.

One of the methods of approaching the problem of determining what is the relative value of the various sensory contributions to the individual's total knowledge concerning motion, was a series of experiments performed in a bank of elevators capable of performing vertically upright trips 40 stories in extent, a height of over 400 feet, at a maximum speed of 1,000 feet per minute. For this purpose four groups of individuals were selected, namely, (1) normals, (2) deaf-mutes totally lacking vestibular perception, (3) deaf-mutes possessing vestibular perceptions in various degrees below the normal, and (4) tabetics whose deep sensibility was impaired to various degrees. These experiments were carried out during a period of six weeks, with a view to determining the average ability of each group to sense the various vertically up and down movements to which they were subjected. The elevator shafts were entirely dark, and the lights on the cars were shut off during the experiments, so that no information reached the individual via the visual tract. Each individual of the normal group was first determined to be possessed of normal vestibular and deep sensibility.

The following is a digest of the findings:

GROUP 1.

FINDINGS IN NORMALS.

ACCELERATION.

1. During acceleration upward all were able to sense accurately the character of the motion to which they were subjected.

SUSTAINED SPEED.

2. A slower sustained rate of speed immediately ensuing upon acceleration upward was uniformly misinterpreted as arrest of motion, or as very slow motion.

RETARDATION.

3. Retardation to the slowest possible continued speed upward, ensuing upon sustained speed upward, was universally sensed as motion vertically downward.

GROUP 2.

FINDINGS IN DEAD VESTIBULE DEAF-MUTES.

4. The deaf mutes in whom the vestibular function was totally abrogated sensed acceleration upward correctly.

5. These individuals were uniformly inconsistent in describing the character of slow motion vertically upward at a constant rate of speed, sometimes guessing " upward " and sometimes guessing " downward," but always acutely sensitive to the fact that they were undergoing motion of some kind.

6. Retardation, ensuing upon motion vertically upward at a sustained rate of speed, was uniformly correctly sensed by these individuals.

7. Arrest of motion ensuing upon retardation or motion at a sustained rate of speed was uniformly correctly sensed by these individuals.

8. In these individuals it was impossible to produce the illusion of reversal of motion by alteration in the speed of the car. It was apparent that absence of hearing and vestibular sense had keyed up to a high degree of attention and sensitiveness the deep sensibility tract, though it is not believed that this observation justifies a statement that the sensing of the deep sensibility impulses was keener than that of the normal individual. It seems certain, however, that the attentions of these individuals to motion perceptions coming in via the deep-sensibility tract were more intense than that of the ordinary normal individual.

GROUP 3.

FINDINGS IN LIVE VESTIBULE DEAF-MUTES.

9. Deaf-mutes in possession of intact vestibular apparatus and normal acuity of perception absolutely duplicated the findings of the first group of full normal individuals tested, as shown in items 1, 2, and 3 of this digest of results.

10. Deaf-mutes in whom acuity of vestibular perception was reduced to an index represented by two or three seconds duration of nystagmus and no past-pointing and almost absent falling were able to sense acceleration vertically upward correctly and failed to identify slower motion at a sustained rate of speed upward, but sensed the motion very positively, though labeling it at times "motion downward" and at other times "motion upward"; they were able to detect retardation and arrest keenly, but did not experience the illusion of reversal of motion either following acceleration, retardation, or arrest of motion.

GROUP 4.

FINDINGS IN TABETICS.

11. Tabetics in whom vestibular tests had demonstrated the presence of normal vestibular functions were roughly of two classes—the lower or dorso-lumbo-sacral type and the higher or the cervico-dorsal type. Both types evidenced a satisfactory ability to sense acceleration of motion vertically upward; slower motion at a sustained rate of speed ensuing upon this acceleration upward was not sensed at all by either type; retardation following motion vertically upward at a sustained rate of speed was sensed as motion downward by both types. Particularly striking was the continuation over long periods of time of the sensing of motion downward by the first type of tabetics when arrest of motion ensued upon retardation vertically upward. Several of these cases continued to indicate motion downward for from 30 to 60 seconds following total arrest of motion. This was not the case with the second type of tabetics, several of whom, however, did indicate sensation of motion downward for a few seconds following total arrest of motion.

DOWNWARD MOTIONS.

12. Acceleration of motion downward from the fortieth floor was correctly sensed by normals, both types of deaf-mutes, and both types of tabetics.

13. Slower motion downward at a sustained rate of speed ensuing upon rapid acceleration downward was sensed by the normals universally, as either complete cessation of motion or extremely slow motion in a downward direction; this was also the case with the second group of deaf-mutes, those in possession of vestibular functions; the first groups of deaf-mutes were unable to sense the character of sustained motion downward accurately, but more frequently guessed "downwards" than "upwards"; the tabetic of either type indicated almost invariably arrest of motion.

14. Retardation downward ensuing upon motion at sustained rate of speed downward was sensed as arrest of motion or as slow motion upward by the normal group and by the deaf-mutes in possession of vestibular function and by both types of tabetics. This confusion of sensing between arrest or slow motion upward was consistent with all members of these groups, but individuals in each group varied in their answers, one individual sometimes indicating arrest and at other times indicating slow motion upward.

15. Arrest of motion ensuing upon retardation downward was uniformly indicated as slow motion upward by the group of normals; the group of deaf-mutes in possession of vestibular function sensed this as slow motion upward only for a second or two and then indicated properly total arrest of motion; the group of deaf-mutes totally lacking vestibular perception uniformly indicated correct perception of arrest of motion on the instant; both types of tabetics indicated sensation of motion vertically upward, and this sensation continued for a much longer period of time than in the normal group.

The conclusions from the above-outlined experiments are that (A) the normal individual, the deaf-mute whose vestibular function is unimpaired, and the tabetics whose vestibular functions are unimpaired seem to be almost equally sensitive to acceleration either upward or downward; (B) during slower motion at a sustained rate of speed upward or downward the deaf-mute whose vestibular function has been totally abrogated is totally unable to sense accurately the character of the motion to which he is subjected, but he is keenly sensible of being subjected to some kind of motion; whether this is vertically upward or vertically downward seems to be pure guesswork. The other individuals tested all evidenced sensory illusion and always in the shape of a relative reversal varying in degree between a sense of partial or complete arrest of motion and inception of motion in the opposite direction. This latter was more marked in the tabetic. This would seem to indicate that in general the quantitative perception of motion at a sustained rate of speed lies more particularly within the province of the deep sensibilities; the qualitative perception—that is, determination of the exact direction of the motion—lies within the province of the vestibular component in the total composite of motion-perceiving. (C) Susceptibility to illusion of a motion-perceiving naturally is directly proportionate to the keenness of the ability to make accurate qualitative perceptions; in other words, the illusions of motion in the absence of vision are largely, if not exclusively, attributable to the vestibular apparatus.

It should be added that for the purpose of conducting these experiments especial control was added to the regular control of these elevators, and by means of this the accelerations, retardations, and motions at sustained rates of speed were accomplished with almost com-

plete absence of jarring or friction. The use of magnetic brake control adjusted to extreme nicety and the elimination of all loose connections and joints eliminated sound almost completely; the visual element of motion-sensing was absolutely eliminated by the conducting of the tests in perfect darkness; tactile impulses were almost completely eliminated by lining the entire car with thick blankets, protecting the subjects from access of air currents to the skin throughout the experiments.

EXPERIMENTAL STUDIES ON "THE FEEL OF THE AIRSHIP."

DEAF-MUTES AND NORMALS.

A physiologic function which is peculiarly important in aviation as contrasted with all other branches of the service is that of equilibration. Nothing could better illustrate this peculiar importance of the inner ear than a comparative study of those with normal inner ears as contrasted with those of destroyed inner ears—deaf-mutes. A series of experiments was conducted in actual flights. Those with normal inner ears, when blindfolded, were able to detect motion changes accurately during the flight, whereas blindfolded deaf-mutes with destroyed labyrinths were not.

In order to appreciate the part that the ear mechanism plays in aviation, all that any physician need do is to take a flight in an aeroplane. As you guide an aeroplane in a straight flight, your incessant effort is to correct minute deviations from the level position; the countless and continuous changes of movement in all directions are counteracted by tiny movements of the joy stick. In your first flights, when instructor is guiding the plane, you watch the joy stick in front of you and you notice that it is moving, ever so little, this way and that, in response to stimuli in the detection of changes of position. This sense of the "detection of movement" is what the experienced aviator calls "the feel of the airship"; it is that sense which distinguishes the born flier from the mechanical flier, who is forced to rely upon his sight in the guiding of the plane. The Almighty gave certain sense organs to man; if there is any individual who preeminently needs a normal sensing of movement, it is obviously the aviator. The turning-chair and douching tests enable us to determine whether the internal ears and all the intracranial pathways from the internal ears are functioning normally.

WHAT IS "FEEL OF THE AIRSHIP"?

One of the terms most commonly used in aviation is "the feel of the airship." It had its origin at the beginning of aviation and seems to be a phrase which in the mind of the practical flier covers everything which goes to express a trained aviator's skill in the proper

and semiautomatic control and balance of an airship. Some men give evidence of possessing this sense-complex during the first one or two hours of instructions; others never acquire it, and still others show it in such a moderate degree that they are always looked upon with apprehension by instructors, who feel that such men are not to be depended upon in an emergency.

Very few trained pilots can give any clear explanation of what is meant by the term, except to say that if the beginner does not possess it he will never be able to make a first-class pilot. Some explain it by a keen sense of motion; some by general physical dexterity, some by a keen sense of vision, and some would seem to credit it to an inborn special sense of some kind. That some such sense or combination of senses exists, there can be no question. This general fact has been appreciated by scientific men from the start, and much of the work of the Medical Research Laboratory has been directed, consciously or unconsciously, toward scientific explanation of this sense-complex.

Evidently motion-sensing must be intimately related with this proper "feel of the airship." As previously stated, motion-sense is dependent upon information derived from (1) muscle sense, (2) sight, (3) vestibular sense, and (4) tactile sense.

OBSERVATIONS UPON MOTION-SENSING DURING AIRPLANE FLIGHTS.

DEEP MUSCULAR SENSIBILITY STUDIED BY ELIMINATION.

The purpose of this study was to try, by elimination of any two of the first three factors, to estimate the value of the third. The fourth, tactile, may be ignored, being constant in all cases. This can be done as follows: Blindfolding eliminates sight; the use of deaf-mutes with destroyed vestibular apparatus eliminates the vestibular sense; blindfolding these deaf-mutes eliminates sight and vestibular sense, leaving the deep sensibility as the remaining factor. Experimental study with cases of tabes and other similar cases, where the deep sensibility is involved, are now being carried on and will give us further data on deep sensibility.

TILTING PERCEPTION.

It has been shown by various observers, experimenting upon thousands of aviation applicants, that there exists a very clear appreciation of tilting. If a chair, balanced on one point, is so slowly tilted that a man seated in it can not sense the motion, there comes a time when he appreciates that he is tilted. Laboratory experiments of this sort have been repeated in the air under practical flying conditions. At first glance it would seem that the experimental errors in such a study would be overwhelming, but a more extended

investigation in the plane, at various altitudes and under various weather conditions, corrects this impression to the extent that for a practical study of the "feel of the airship," theoretical experimental errors can be disregarded.

POINTS IN EXPERIMENTS TO BE NOTED.

In order to get at normal responses under actual air conditions, five points must be observed: (1) Subjects with previous flying experience must be eliminated; (2) normal individuals must be selected, who are not alarmed by the thought of a first flight, and who have trained powers of observation; (3) a professional pilot of years of flying practice must be used whose experience would enable him to appreciate the problems and hold the ship at the given angles with the greatest degree of accuracy in spite of unfavorable atmospheric conditions, and a clinometer used by him to measure angles of tilt; (4) the same plane must be used throughout the experiments; and (5) the intercommunicating phone system must be used between pilot and subject.

KIND OF SUBJECTS SELECTED.

For purposes of study, 15 candidates were selected from the Surgeons in the Medical Research Laboratory. Chart I is a graphic diagram of the results of the experiments on normal individuals who have never had any previous experience in the air. The subjects were blindfolded, were then taken up in the plane, and the maneuvers indicated were carried out. The lower blue line shows the movements actually executed by the plane. The upper red broken line shows the movements the subject felt were being executed.

EXPLANATION OF CHARTS I AND CHARTS II AND III.

There is a very important difference in the nature of carrying out the maneuvers in Chart I and Charts II and III. In the first type of experiments, conducted in Chart I, the positions were changed by markedly quick movements of the plane, i. e., the upward motion was the sudden zoom upward, the downward motion was a quick almost vertical dive downward, the banks to the right and left were done quickly, and the turns on the horizontal plane were made as sharp as possible.

If a quick zoom is made, the feeling is that you are being thrown against the seat by centrifugal force and in a quick steep bank a similar sensation is noticed. In the start of the nose dive one is thrown against the belt by the action of the centrifugal force, and it is not a matter of wonder when the candidate interchanges in his mind movements in which the most prominent element is the centrifugal action forcing his body against seat or belt. We also found

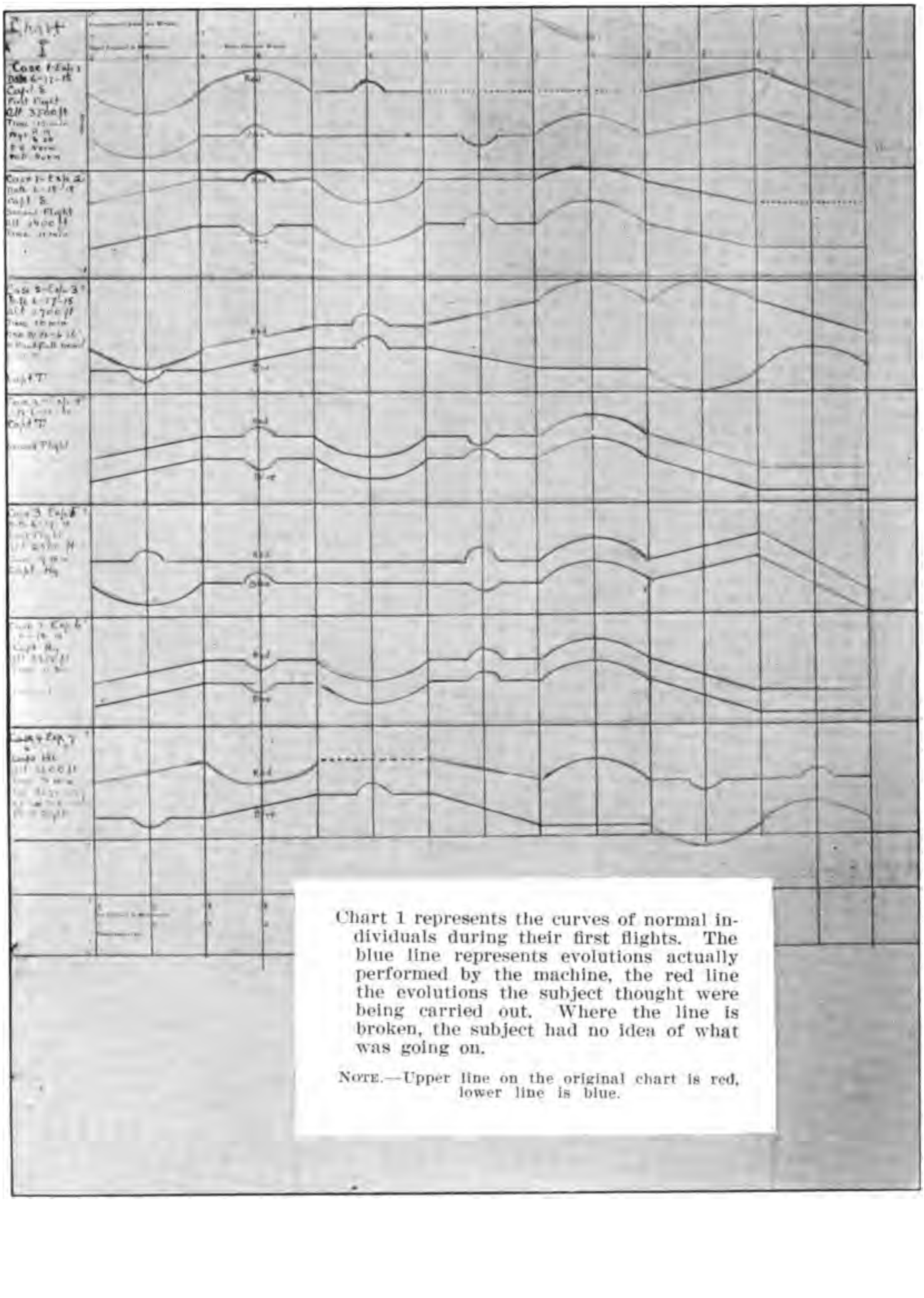


Chart 1 represents the curves of normal individuals during their first flights. The blue line represents evolutions actually performed by the machine, the red line the evolutions the subject thought were being carried out. Where the line is broken, the subject had no idea of what was going on.

NOTE.—Upper line on the original chart is red, lower line is blue.

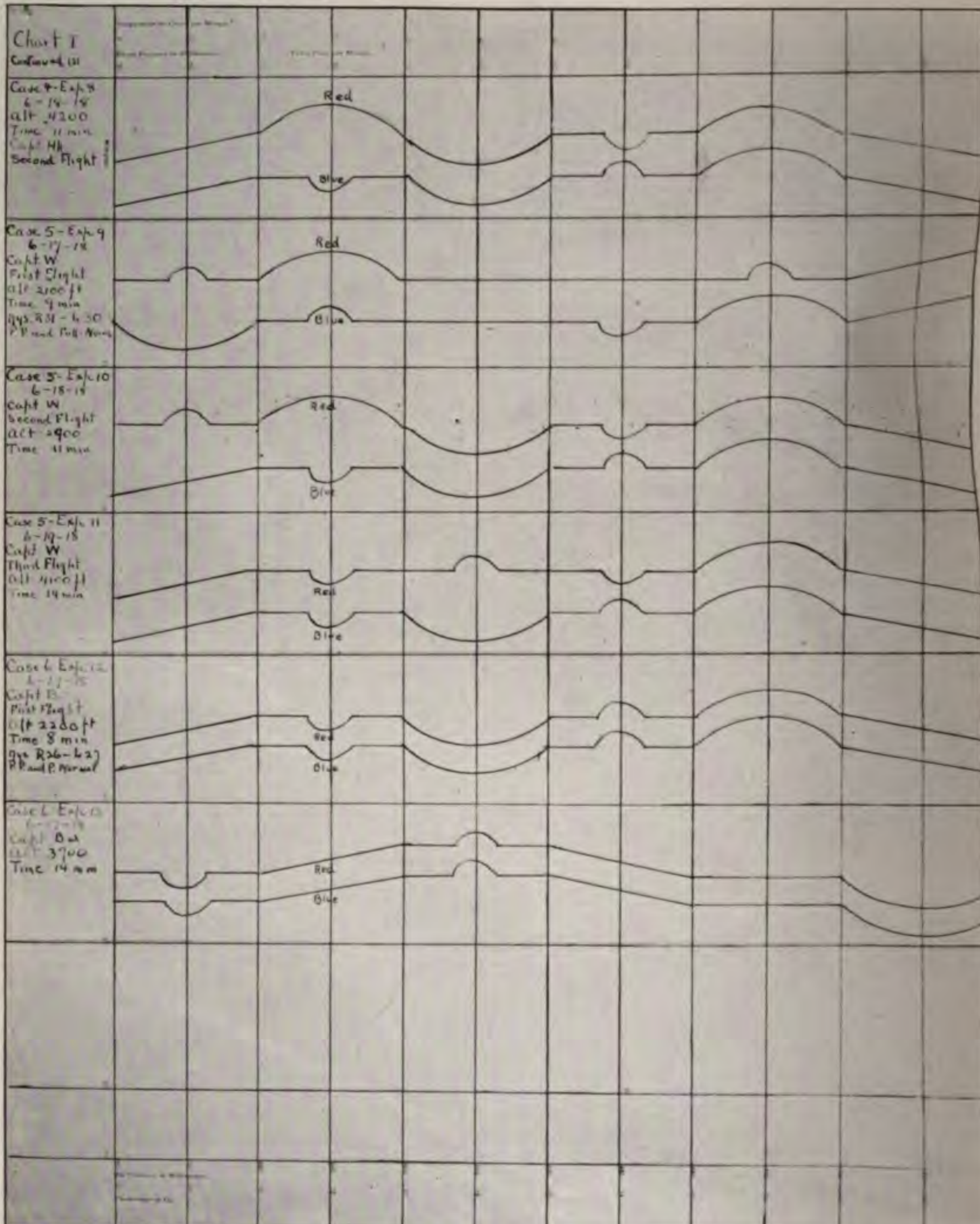
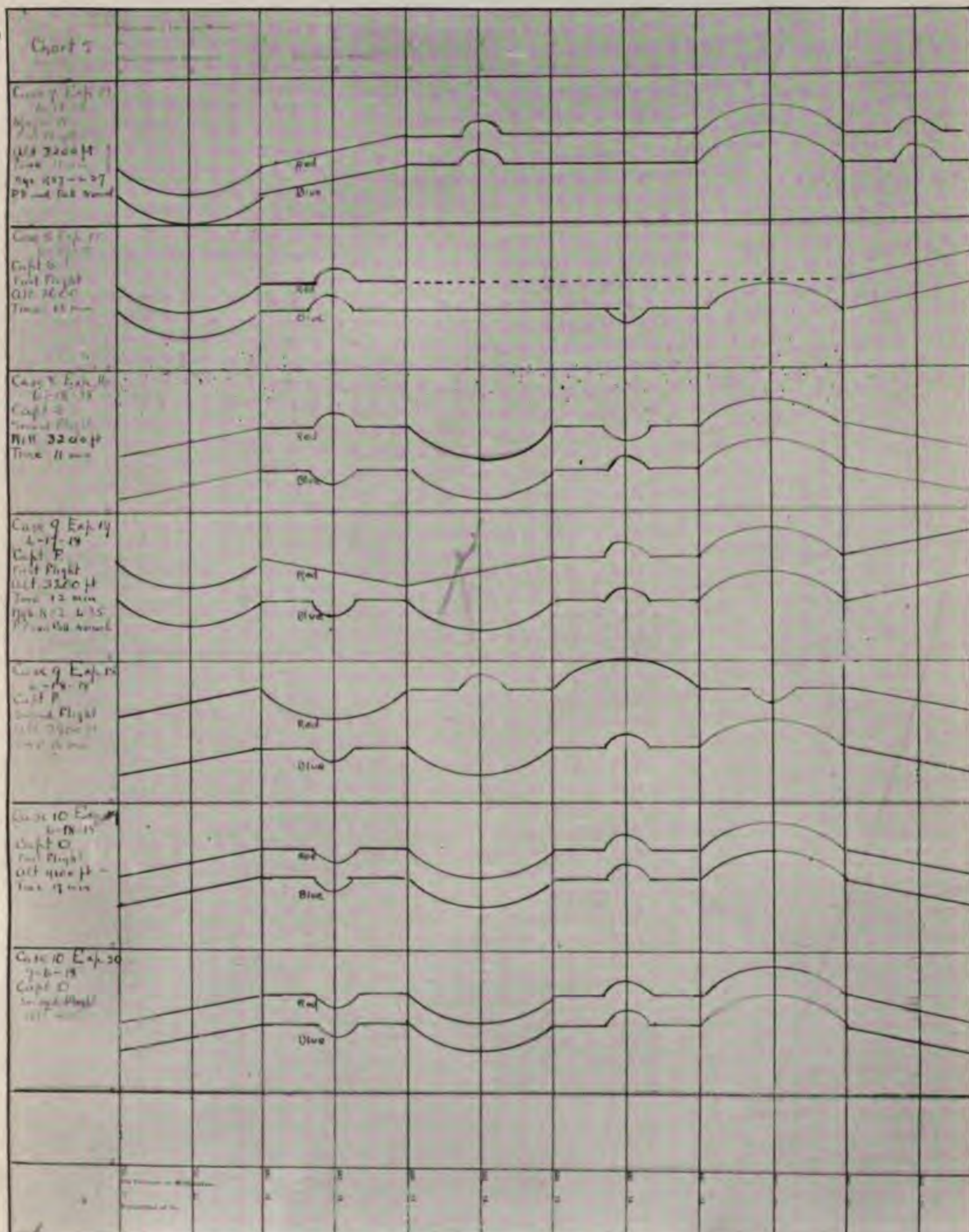


Chart I
Case 5 - Exp 9
Capt W
First Flight
Time 9 min
Case 5 - Exp 10
6-18-18
Capt W
Second Flight
Case 5 - Exp 11
Capt W
Third Flight
Time 14 min
Time 8 min
Time 14
Red
Blue


Case 9 Exp 19
6-17-18
Capt P
First Flight
Alt 3200 ft
Time 12 min
Case 9 Exp
Capt P
Second Flight
Case 10 Exp
6-18-18
Capt O
First Flight
Case 10 Exp 20
Capt O
Red
Blue

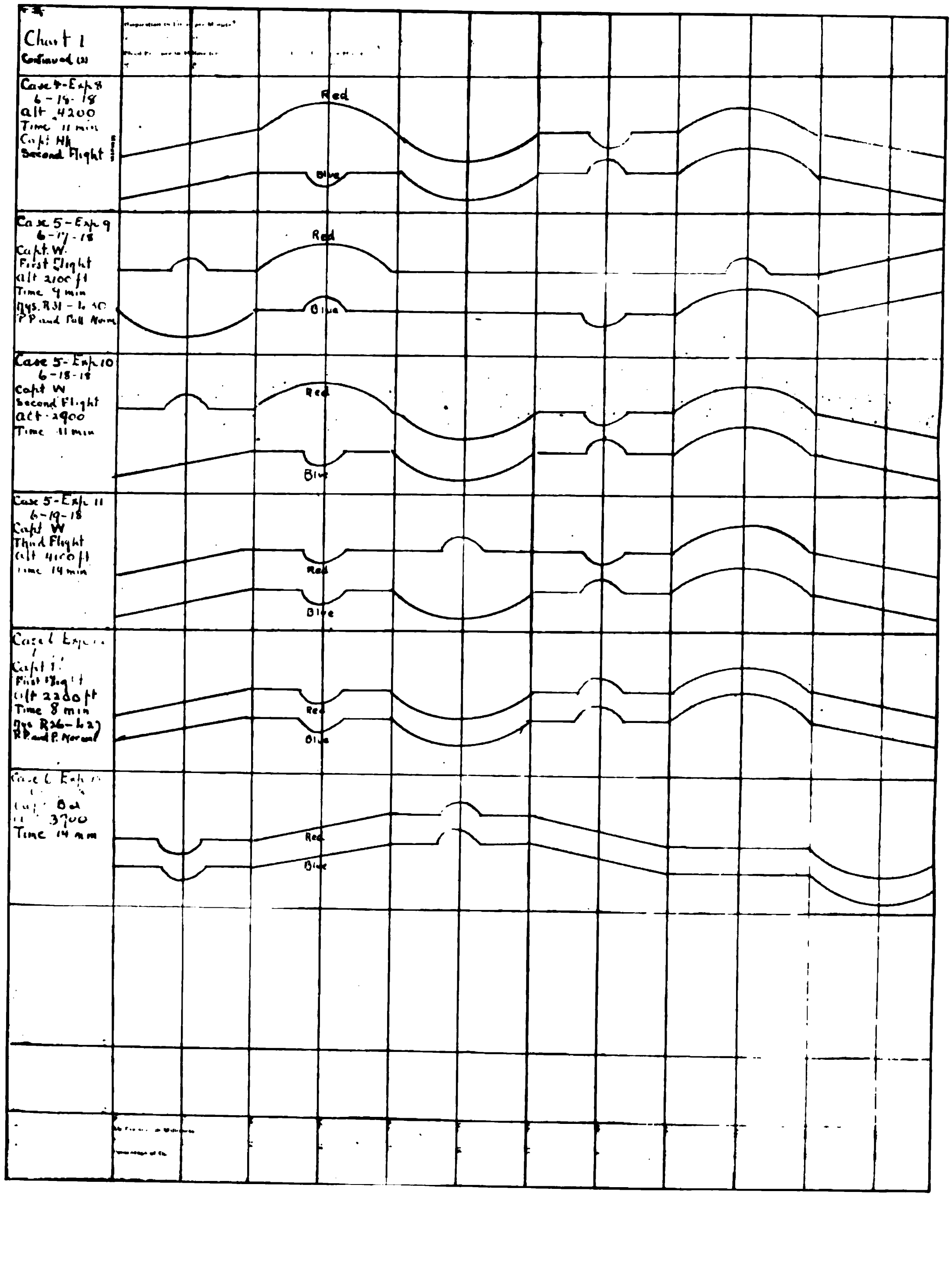
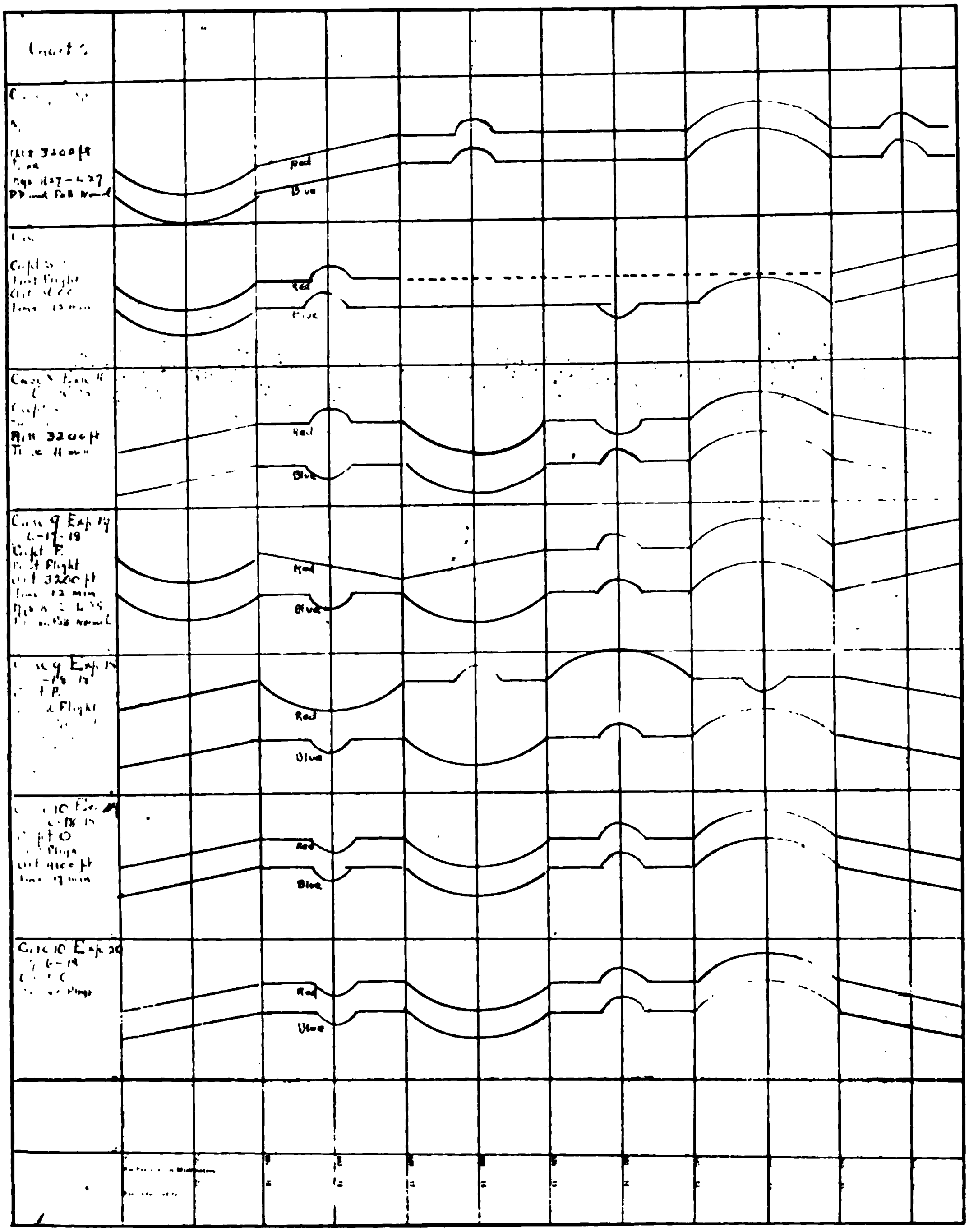


Chart 1
Continued (2)
Case 4-Exp 8
6-14-18
alt 4200
Time 11 min
Second Flight
Red
Blue
Case 5-Exp 9
6-17-18
Capt. W.
First Flight
Time 4 min
Case 5-Exp 10
6-18-18
Capt W
Second Flight
Time 11 min
Case 5-Exp 11
6-19-18
Capt W
Third Flight
time 14 min
First Flight
alt 2200 ft
Time 8 min
3700
Time 14 min


Red
Blue
Case 9 Exp 19
Case 10 Exp 20

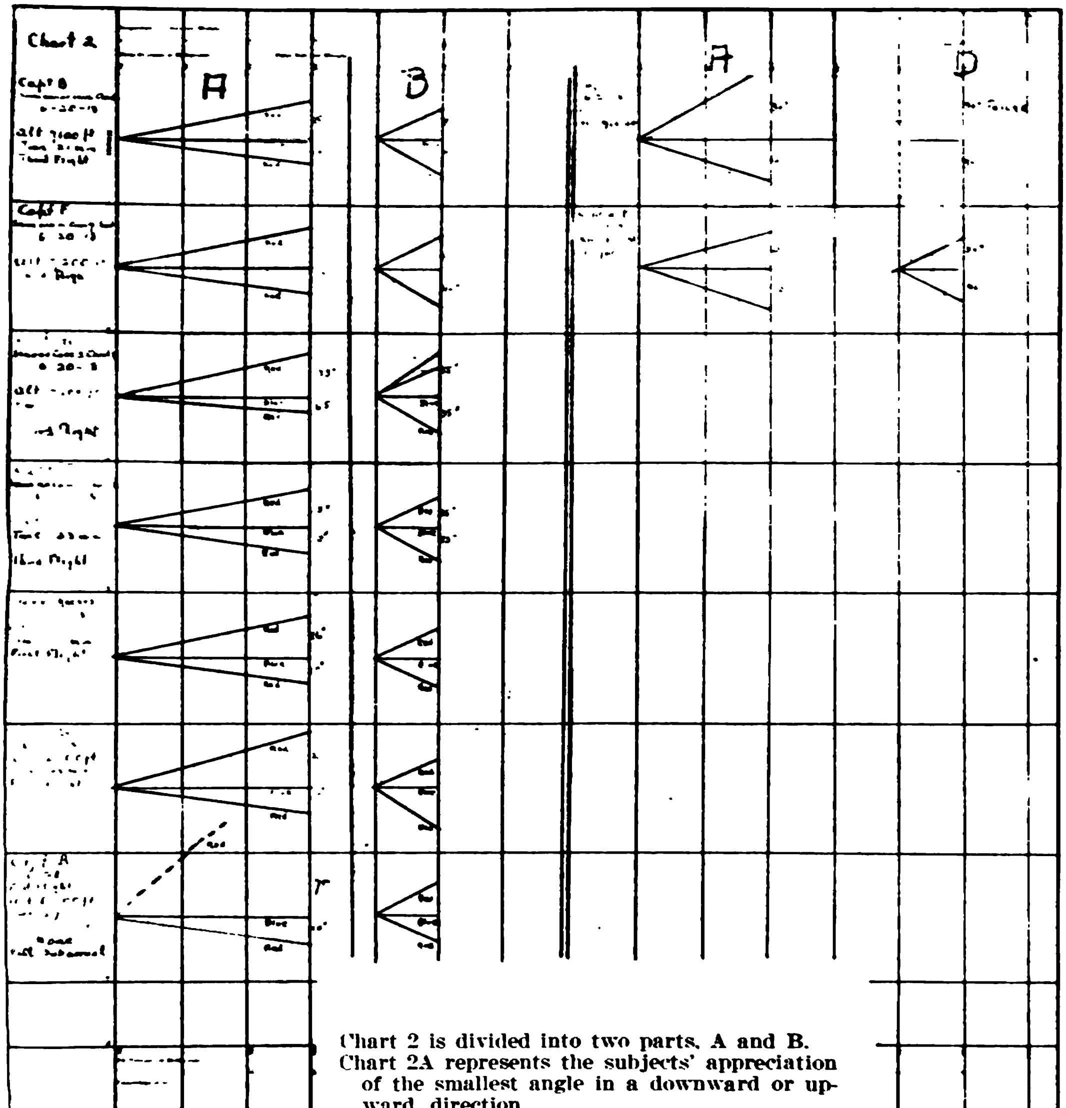


Chart 2 is divided into two parts. A and B.
Chart 2A represents the subjects' appreciation of the smallest angle in a downward or upward direction.
Chart 2B represents the subjects' appreciation of the smallest angle in a bank.
The stalling angle of the machine, past which it is unable to execute these evolutions is 70 degrees up. 40 degrees down. 85 degrees on the banks.

Case VIII, experiments 15 and 16, Chart I.—A fair observer only. In his first flight he did not try to guess as many of the more nervous ones did, therefore the dotted line. The second flight showed improvement, making only one fundamental error.

Case IX, experiments 17 and 18.—A man over 50 years of age, was very nervous about his first flight, but improved somewhat during the second, still making several fundamental errors.

Case X, experiments 19 and 20, Chart I.—A trained physiologic observer, cool and calm, and made no mistakes of any kind.

Case XI, experiment 21, Chart I.—Highly strung young man, very tense; made only one error on his only flight.

EXPLANATIONS OF CHART II, III, AND IV.

Charts II, III, and IV represent a study of the ability to detect gradual departures from the horizontal flying line. In contradistinction to the first series of observations the endeavor here was to make the change in the angles so gradual that the candidate would appreciate his change from the horizontal in addition to sensing the forward movement of the plane. The endeavor was to eliminate suddenness in change of direction as much as possible. They were conducted with the greatest care and only during ideal weather. The angles were checked by using a clinometer and every effort possible was made to eliminate experimental error. The intercommunicating phone system was used. As soon as a proper altitude was reached, where the air was smooth, the subject blindfolded himself and as soon as he was able to appreciate whether he was going up or down, or banking to the left or to the right, he would so report to the pilot. The pilot would then maneuver the plane to repeat this angle from 6 to 10 times or until he was positive of the smallest angle that the subject was capable of appreciating, when he would write down his result. The remarkable similarity of the results is in itself proof that the experimental errors were slight, or at least were about equal in all cases and, therefore, to be neglected.

CHART 2–A.—OBSERVATIONS UPON MOTION-SENSING DURING AIRPLANE FLIGHTS.

In this series of experiments some of the subjects had never flown, while others had had a few flights previously in the other series of experiments. It is to be noted that in this series the downward angle was detected in every case more accurately than the upward angle; the upward angle was less accurately detected by men making their first flight. One of these beginners was unable to detect the upward angle even to 70 degrees, the stalling angle of the machine. Subsequent examination showed that this man's vestibular reactions were very much subnormal, as evidenced by 10 seconds' duration of nystag-

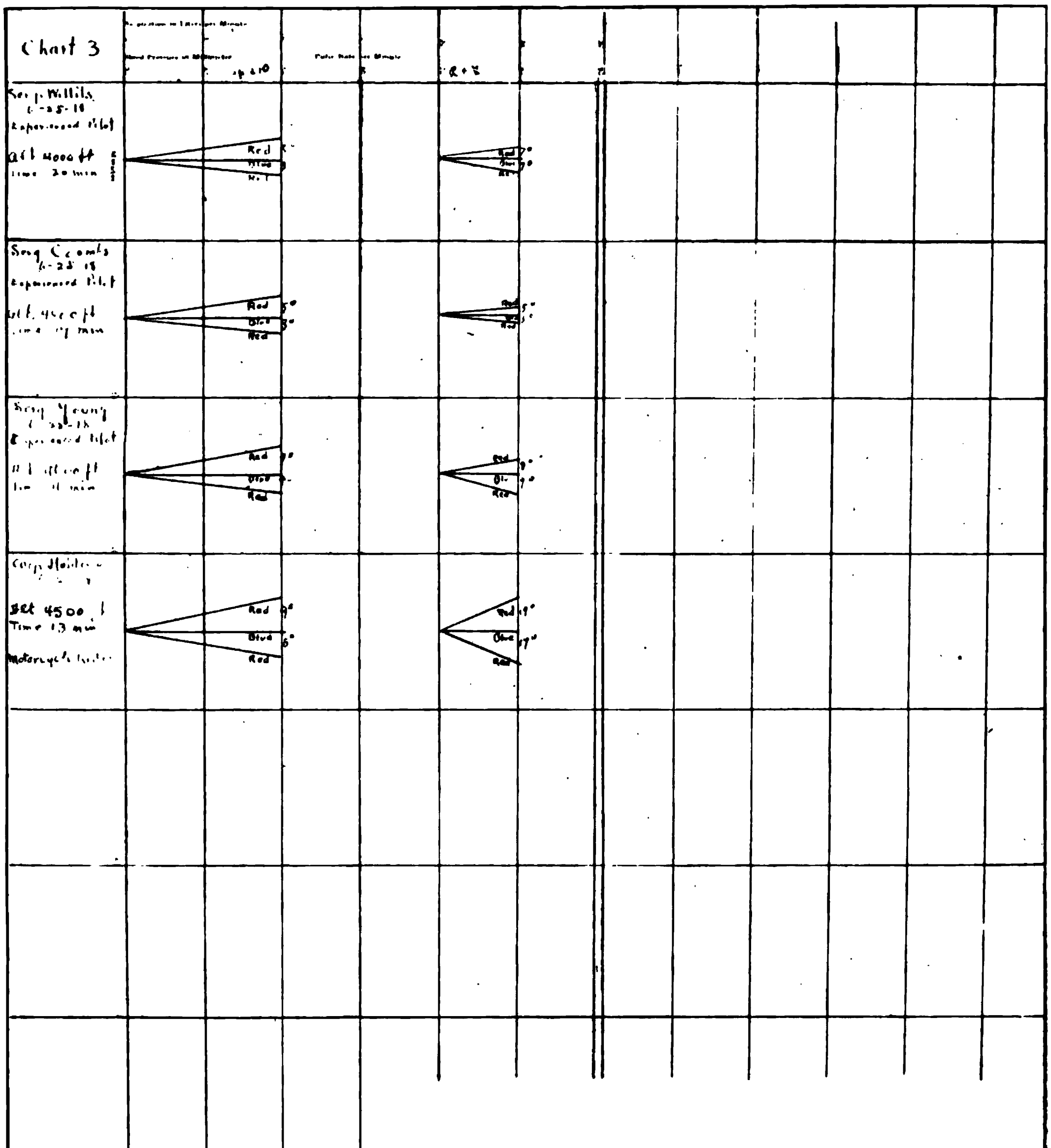


Chart 3 illustrates the appreciation of angles by professional fliers.

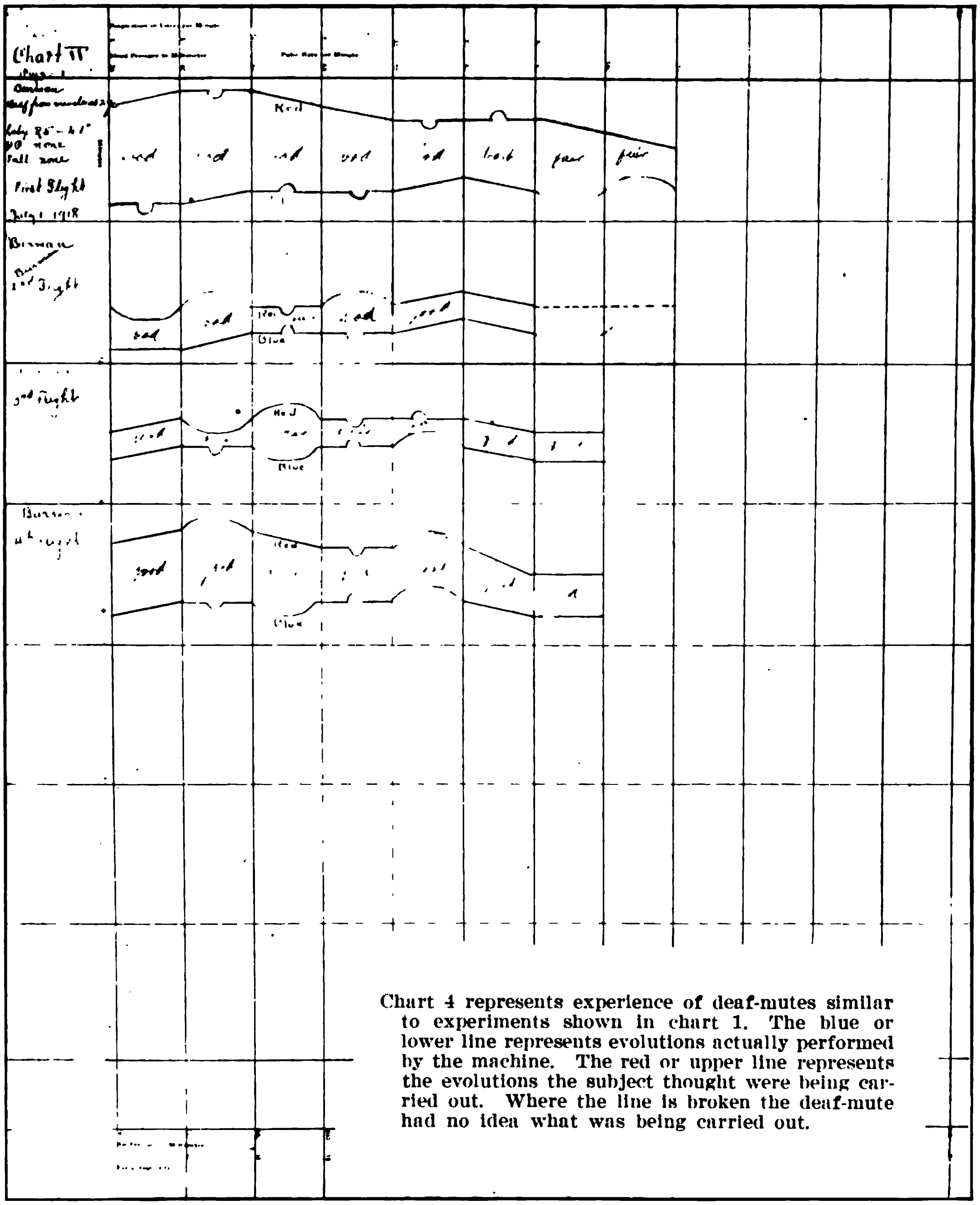


Chart 4 represents experience of deaf-mutes similar to experiments shown in chart 1. The blue or lower line represents evolutions actually performed by the machine. The red or upper line represents the evolutions the subject thought were being carried out. Where the line is broken the deaf-mute had no idea what was being carried out.

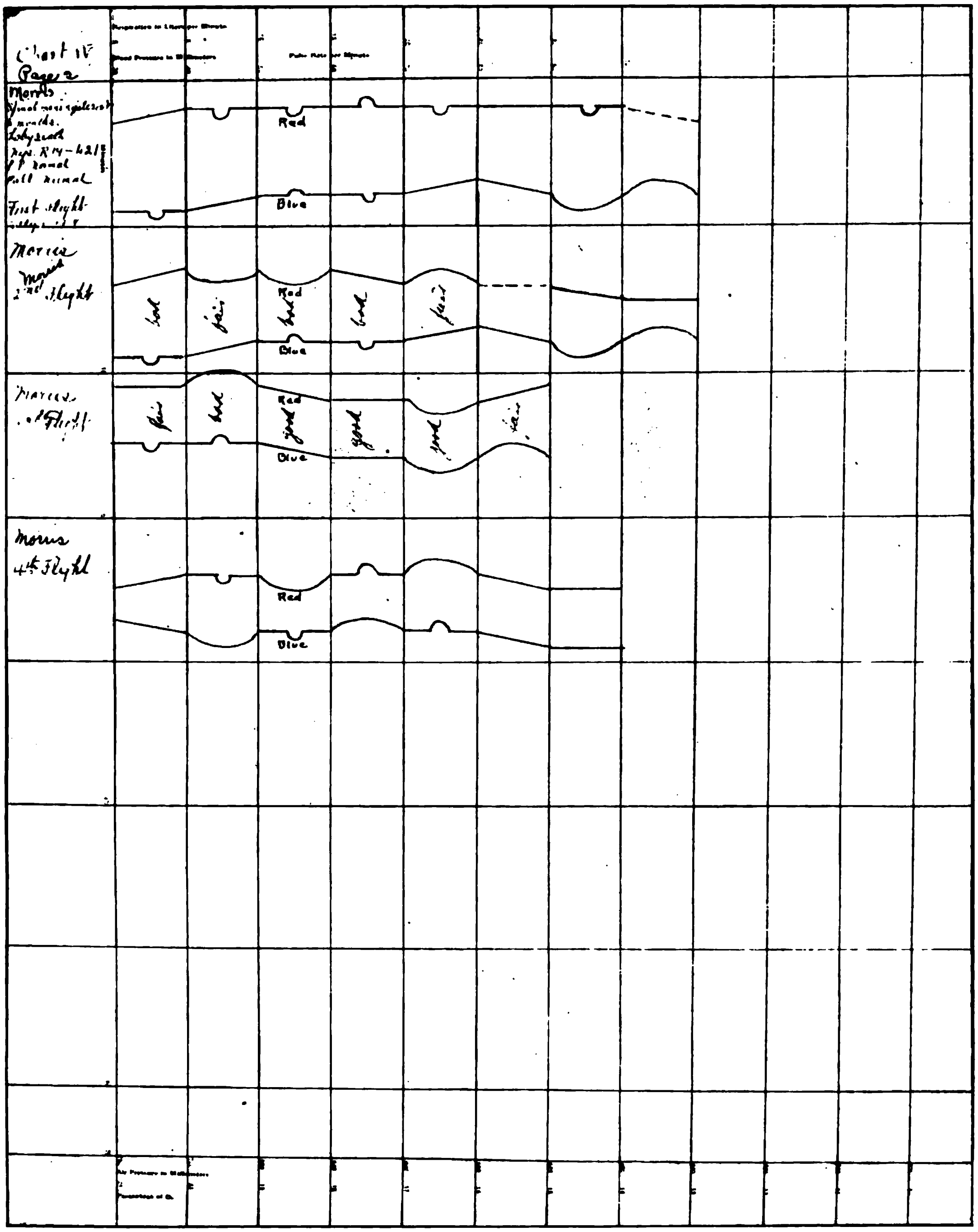


Chart IV
Page 2
Morris
First flight
Morris
2nd Flight
Morris
4th Flight
Red
Blue
bad
fair
good

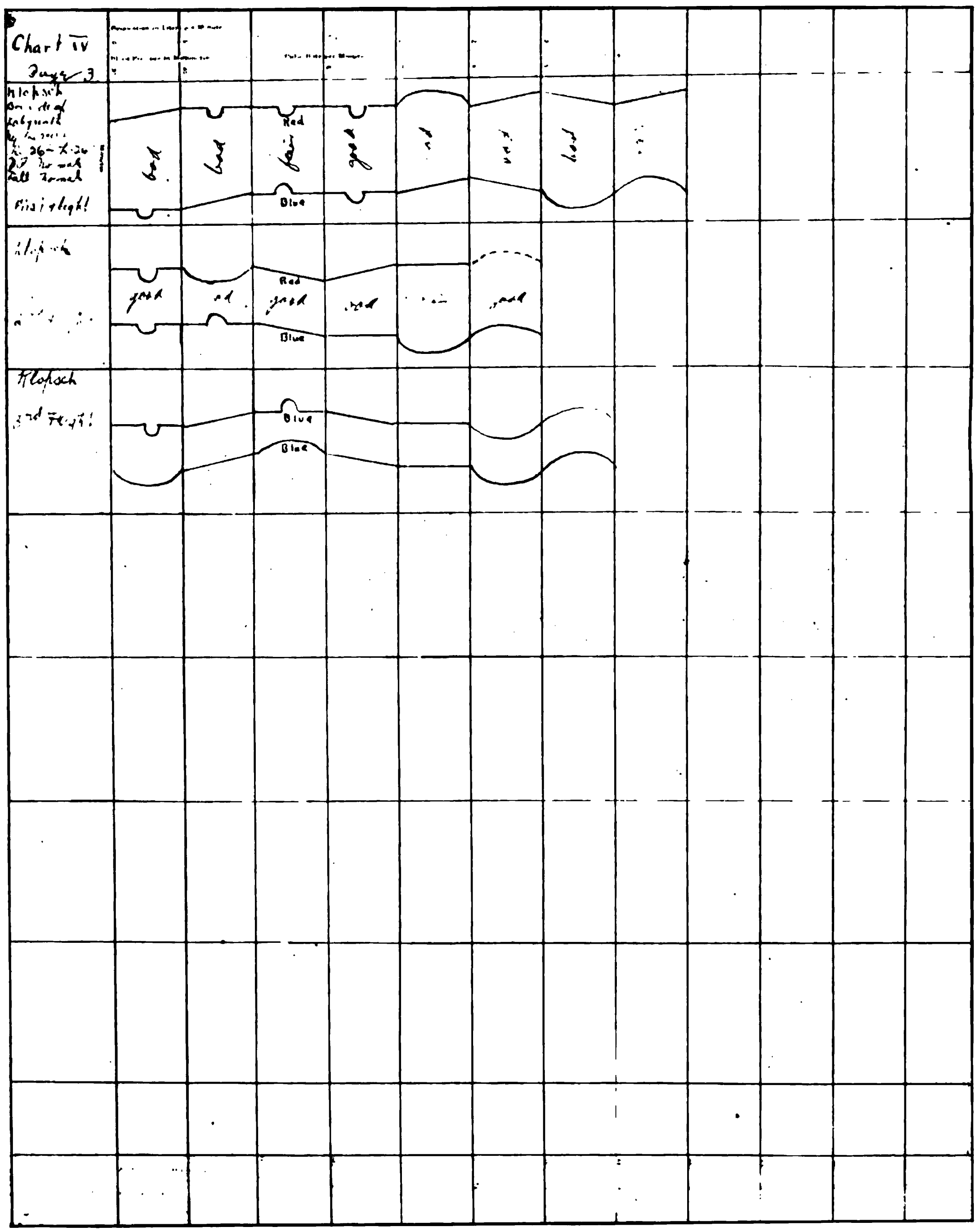


Chart IV
Klopsch
First flight
bad
bad
Red
fair
good
Blue
good
Red
good
Blue
good
Klopsch
3rd Flight
Blue
Blue

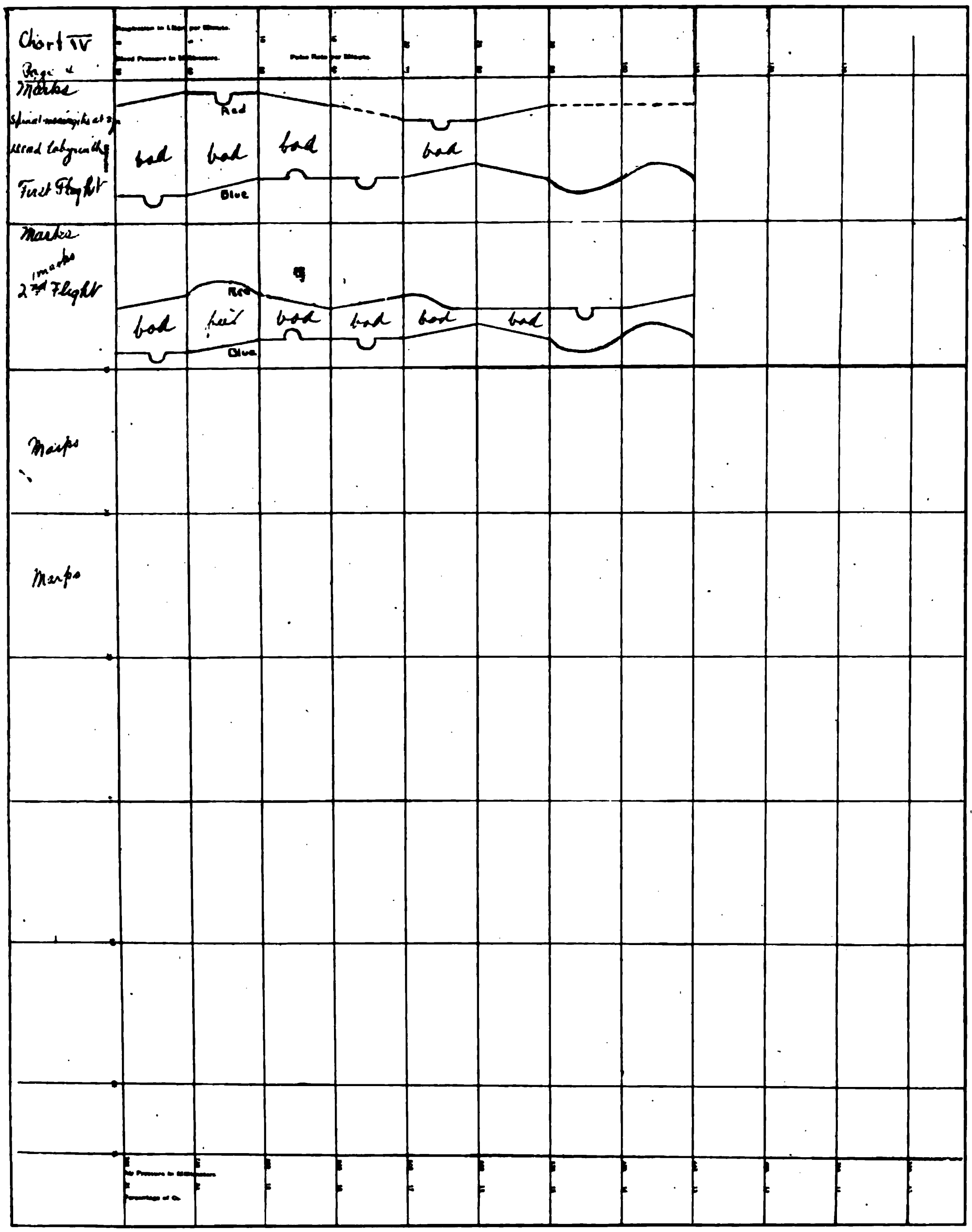


Chart IV
Marks
bad
bad
bad
bad
Red
Blue
First Flight
Marks
2nd Flight
bad
fair
bad
bad
bad
bad
Marks
Marks

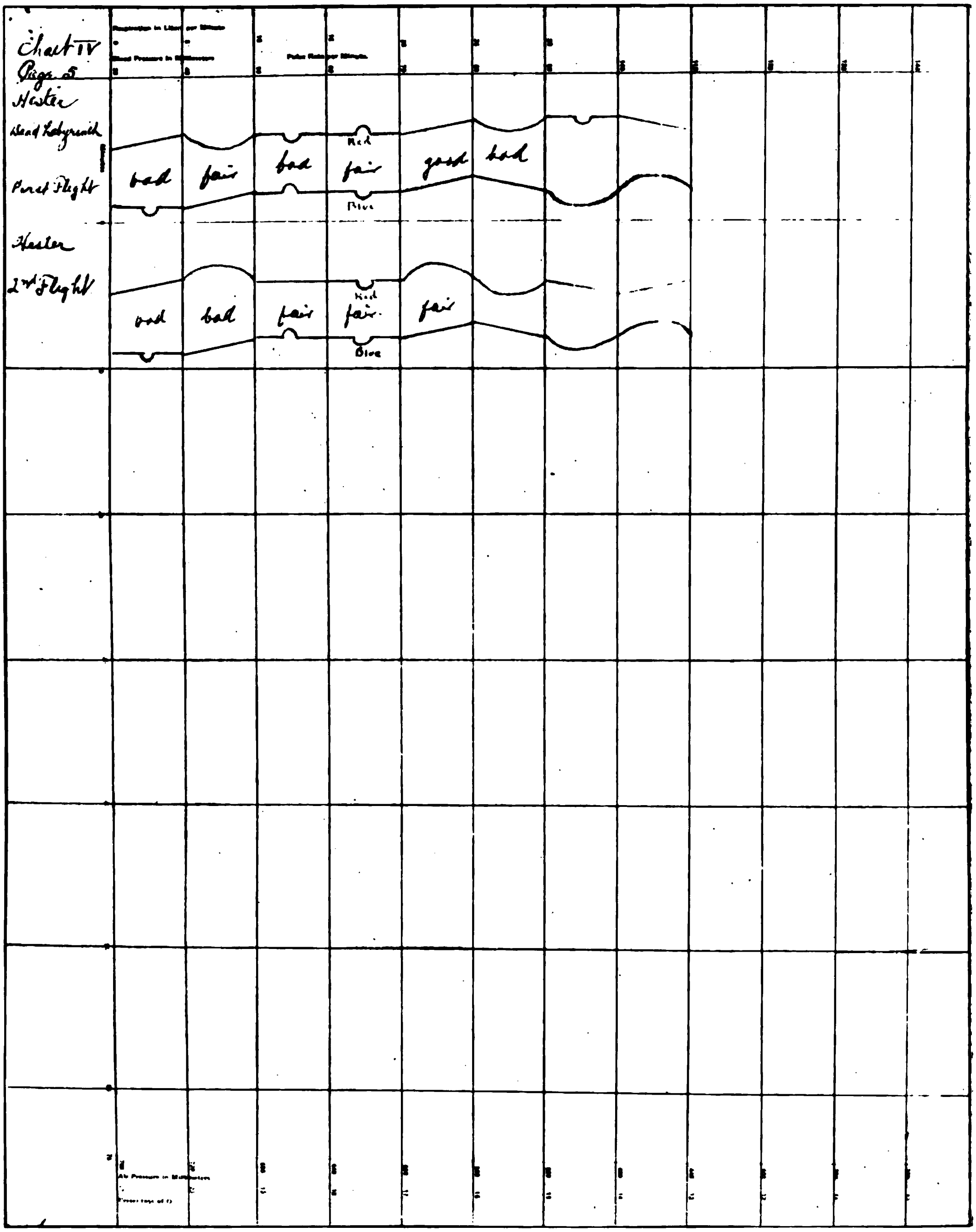


Chart IV
Page 5
Hester
Head Labyrinth
First Flight
Hester
2nd Flight
bad
fair
bad
fair
good
bad
Red
Blue
bad
fair
fair
fair
Red
Blue

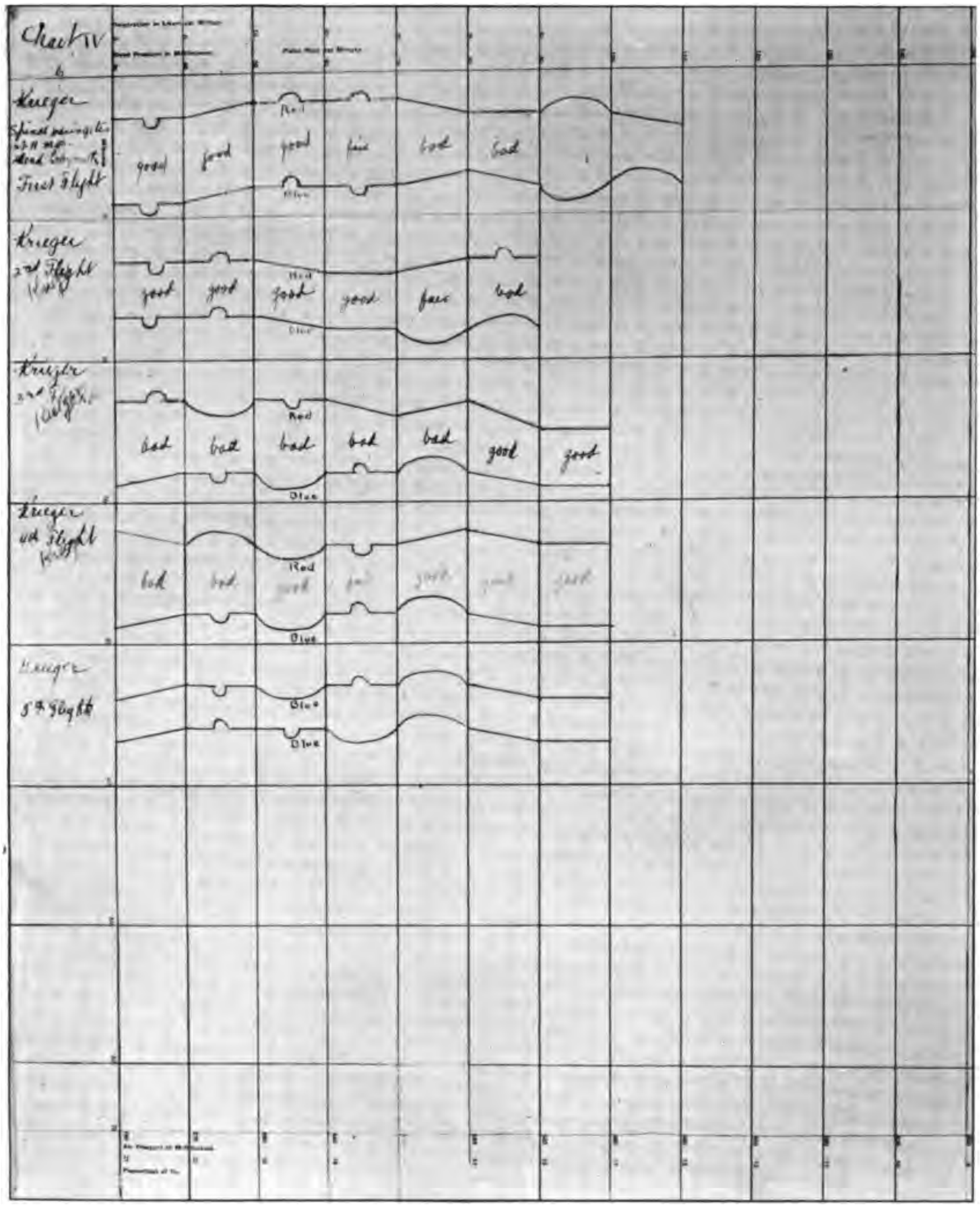
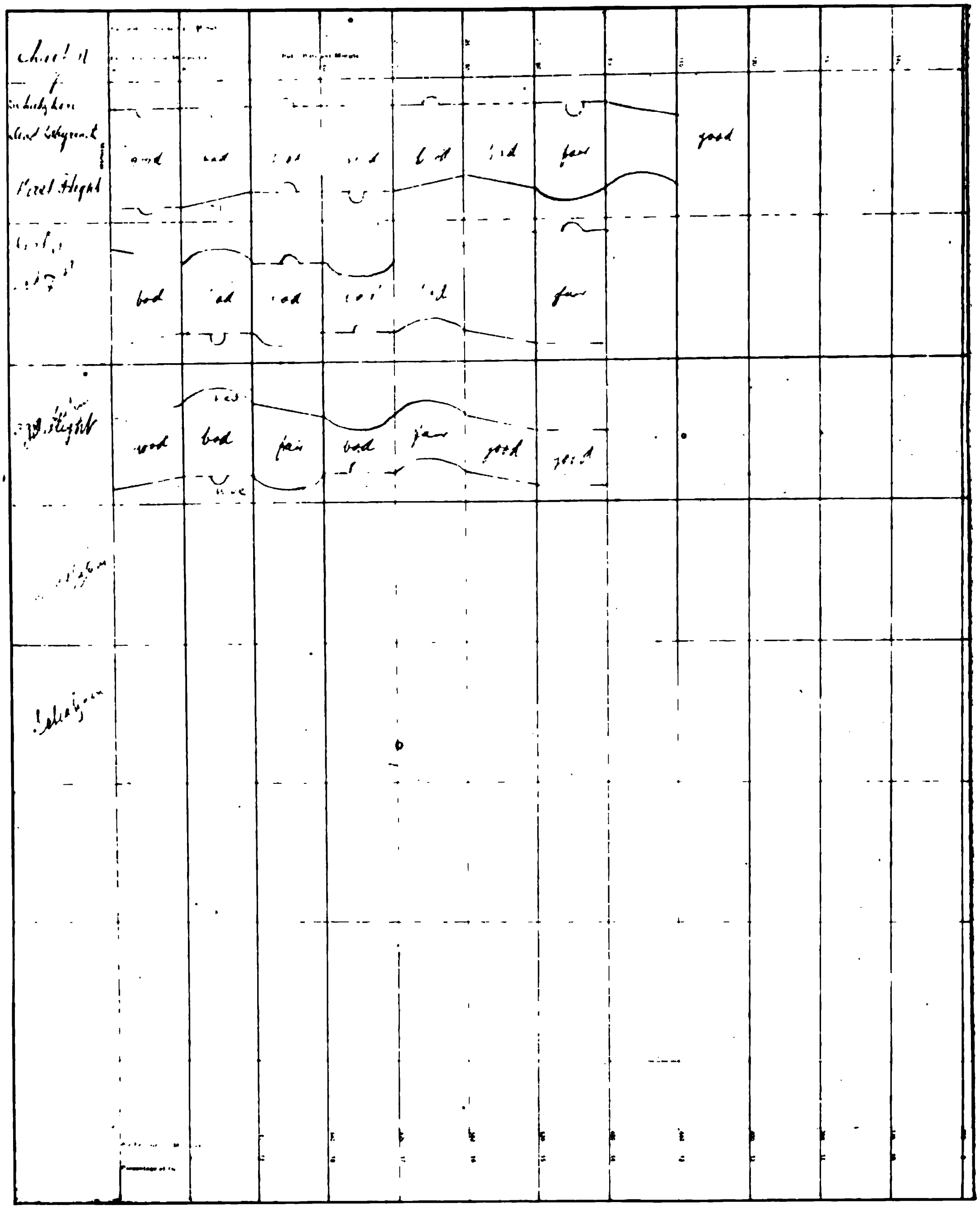


Chart IV
Krueger
First Flight
good
good
good
fair
bad
bad
Red
Blue
Krueger
2nd Flight
good
good
good
good
fair
bad
Red
Blue
Krueger
3rd Flight
bad
bad
bad
bad
bad
good
good
Red
Blue
Krueger
4th Flight
bad
bad
good
good
good
Red
Blue
Krueger
5th Flight
Blue
Blue



good
fair
bad
fair
bad
fair
bad
fair
good

mus, no past-pointing, and only very slight tendency to fall. The general average of these upward and downward experiments show upward angle, 17 degrees; downward angle, 9 degrees.

CHART 2–B.

Chart 2–B represents a series of experiments similar to those just described, except that the angles were banking (lateral) angles instead of upward and downward (forward) angles. This series of experiments showed a similarity in the ability to detect lateral changes from the horizontal. A curious development was that in this series the banks to the left were more accurately detected by the subjects than similar banks to the right.

CHART 4.

Chart 4 shows the most interesting results of all. Seven deaf-mutes were the subjects of these experiments. Two showed normal vestibular function, four showed absolute lack of vestibular function, and one showed a very small amount of vestibular function as represented by three seconds of nystagmus. The results of these experiments upon deaf-mutes are further divided into three groups. The findings of the first groups, those with absolutely no vestibular function, showed total inability to detect changes in the series of movements of the plane in any of the six flights per individual. The results of experiments with the second type of deaf-mutes, in which only a vestige of vestibular function remained, are almost identical with those of the first group. The third type of deaf-mutes, in full possession of vestibular function, showed, however, a marked improvement over the others in successive flights, and practically the normal index as to accuracy of detection of the movements of the plane in the later flights.

CHART III.

Chart III consists of a series of observations carried out under the same conditions upon three professional fliers and one professional trick motor-cyclist. Their superiority in detecting angles is at once apparent. Still more interesting is the fact that the motorcyclist, who had practically no flying experience, did not detect angles as well as the pilots, but still appreciated them better than did other subjects inexperienced in balancing.

Other experiments with other normals, not noted on these charts, convinced us that the results so far given represent very accurately the general average in such individuals, and, therefore, experiments of a greater number were not considered necessary for this preliminary study.

DEAF-MUTE EXPERIMENTS.

CHART IV.

Chart IV is, as has been said, the most interesting of all. Seven deaf-mutes were selected whose labyrinth findings are given on the edges of the charts. The striking differences between these deaf-mutes and the normal candidates and the still more striking lack of improvement in all their subsequent flights seem to be fairly convincing that for purposes of appreciating changes of position in space a properly functionating vestibular apparatus is of great importance, and further, but little can be expected from deep sensibility when it alone senses motion. These deaf-mutes were all highly interested and were keenly alive to the experiments. Some of them were convinced that they would prove able to qualify for aviation, and when their charts were shown to them their amazement was extreme. Their guesses as to the kind of motion to which they had been subjected were of the wildest character. They had nothing to inform them except their deep sensibility and tactile sense. Nose dives and the "zoom" or upward movements were carried out at such acute angles that it was remarkable that they guessed as inaccurately as they did. On close questioning many of them admitted that they were entirely "in the dark" and felt as if they must tear the bandage from their eyes; in other words, they were completely lost in space, and it is greatly to their credit that they were willing to subject themselves repeatedly to these more or less trying experiences.

One of the most important observations of all is seen in an examination of Chart V. As a matter of interest, before these subjects were sent up, we tried them walking a straight line blindfolded, which they did in a fairly accurate manner, but when they were asked to maintain themselves in equilibrium by standing on one leg with eyes closed, they fell in various directions and none of them were able to stand at all steadily in this position. After rapid rotation with the head forward and eyes closed, they were quite as able to stand as they had been before, showing no tendency toward the normal falling response. They were dependent for sensory information in walking or standing on one leg, etc., upon only two sources—vision and deep sensibility.

In the angle experiment, shown on Chart V, where rapid acceleration of motion was made, not a single subject was able to guess a single correct position in space. The machine was brought up to the stalling angle above, to the extreme diving angle below, and to such an acute bank that the vertical control became the rudder, and because the change was gradually brought about, they were still unable to appreciate any deviation from the horizontal. This preliminary

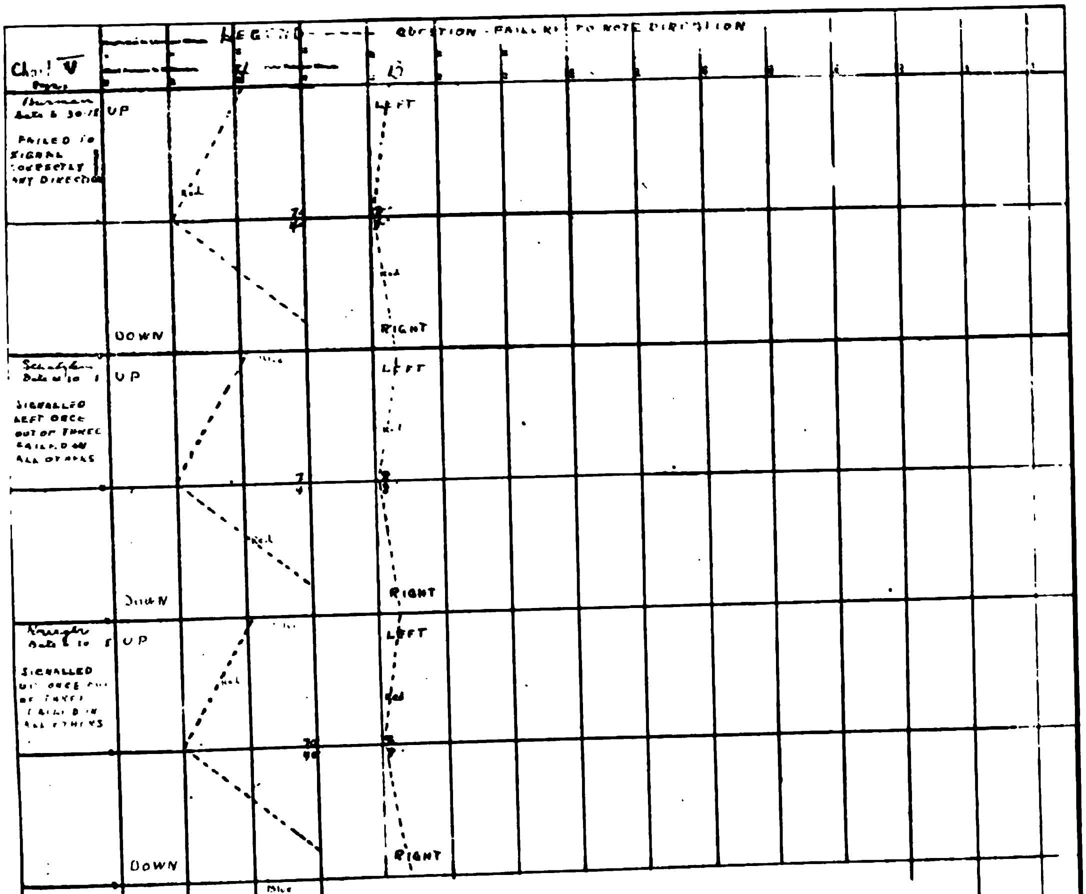


Chart 5 represents for deaf-mutes what chart 2 represents for normals.

Chart 5A represents the subjects' appreciation of the smallest angle in downward or upward direction.

Chart 2B represents the subjects appreciation of the smallest angle in bank.

The stalling angle of the machine, past which it is unable to execute these evolutions is 70 degrees up, 40 degrees down, 25 degrees on the banks.

It is to be noted that in no case was the deaf-mute able to appreciate any of these angles. Therefore, all of the lines are broken.

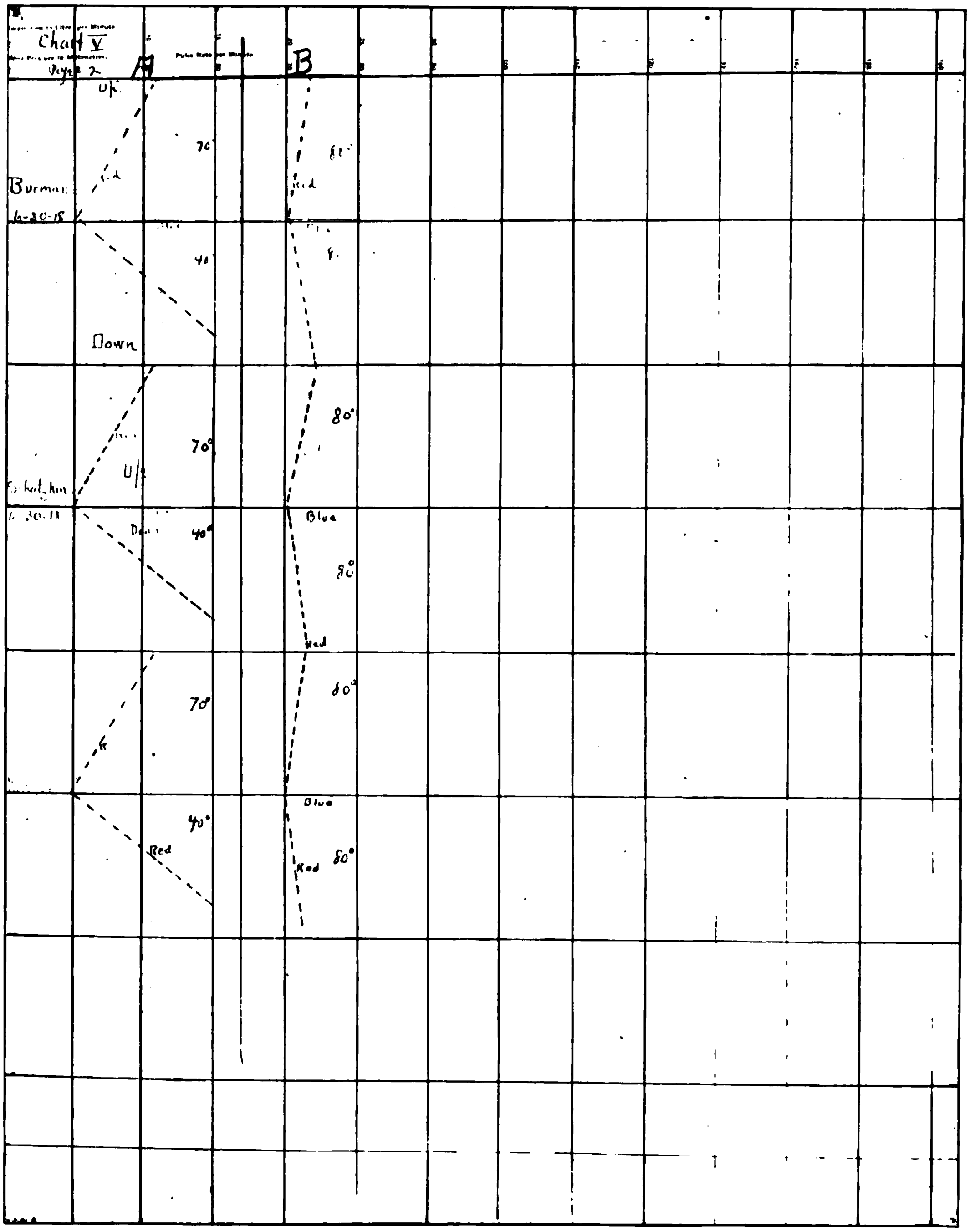


Chart V
Page 2
A
B
Pulse Rate per Minute
Up
70°
Burman
6-30-18
Down
70°
80°
Up
40°
Blue
80°
Red
70°
80°
Blue
40°
Red
Red
80°

study was made in the hope that the peculiar impression which has gone abroad and which has done much to block the progress of the selection of aviation candidates—that the less acute motion-sense of the inner ear was the less dizzy, and therefore the better flier the man would make, would be corrected.

The findings (covering seven days of experimental work, including 52 flights) as to the motion-sensing of the two deaf-mutes with normal vestibular reactions give undoubted evidence of gradual improvement in correct sensing of motion; one deaf-mute with a vestige of vestibular function shows some improvement in ability to sense motion correctly; four deaf-mutes with no vestibular function show no evidence of improvement in motion-sensing ability. It must be borne in mind that such a series of experiments should be much greater and should cover a much longer period of time if deductions of a final nature are to be drawn. The injection of so many extraneous influences, such as apprehension, fear, excitement, inability to focus attention, vitiates to a considerable extent the value of the findings in any individual flight. On the other hand, guesswork injects an additional element of unreliability into the findings. While analysis of the charted records shows some surprising inconsistencies, it is at once apparent that normals show no such diametrically opposite consecutive motion-sensing perceptions as the deaf-mutes. It is demonstrated by this series of experiments that man's ability to sense motion is measured by his full possession of visual acuity, deep sensibility, vestibular sense acuity, and tactile sense. And particularly, that the " feel of the airship " which is the sense-complex that makes for a first-class pilot, requires normal vestibular motion-sensing.

4. Experience and Education in Motion-Sensing and Fatigue of the Vestibular End-Organs.

The possibilities of a person accustoming or educating himself by constant rotation to estimate correctly the sensations of vertigo or disturbed relations in space have been considered, and experiments were carried out with a view to shedding light upon this question. The matter is one of practical importance, and upon it the life of an aviator may depend in a critical moment. Adjustment in seasickness, in whirling dances, in acrobatics, and in any other line of work where rapid changes of spacial relations are necessary has long been known. It has been a disputed point as to whether the duration of the nystagmus in such cases actually becomes less and less with the same stimulus. By experiment it was found that nystagmus occurs less in duration after repeated turnings, and the sensation of vertigo becomes less intense. The immediate shortening of duration of nystagmus and the lessening of vertigo in whirling dancers or others ensuing upon excessive stimulation of the vestibular end-

organs is a transitory fatigue phenomenon. The average normal, whose nystagmus time when not fatigued is approximately 24 to 26 seconds, is the man who is physically most suitable for flying training. Many experiments concerning acute and chronic fatigue phenomena are now under consideration in this laboratory and will be reported upon later. (*See Editorial Insert, p. 193.*)

The whirling artists, who spend years in professional whirling acts, when not fatigued show full normal responses to tests of their vestibular apparatus. Their art lies in the education and experience which they have gained and in the dexterity they have acquired in the repeated performance of their acts. For instance, a whirling dance may be creditably performed by a novice, but the professional whirling dancer will demonstrate his ability to stop dead still suddenly without a fall, whereas the novice will fall, because of the vertigo (or false sense of motion) he experiences as a result of his whirling. The difference between the artist and the novice lies in the artist's ability to place proper construction upon his false sense of motion, experience and education enabling him to estimate its degree of falsity so correctly that he is able to calculate his voluntary muscular control in a manner that results in his accomplishing a successful standing still. The novice, unpracticed and inexperienced in estimating vertigo, finds himself unable to do so successfully and falls to the floor.

TESTS OF WHIRLING ARTISTS, DANCERS, AND EQUILIBRISTS, FEB. 28, 1918.

"*L. L.,*" *whirling artist.*

Nyst. R. 26 sec., L. 24 sec.

P. P.	To R.	R. hand 5.
		L. hand 4.
	To L.	R. hand 3.
		L. hand 3.
Falls		R. normal.
		L. normal.

"*J. S.,*" *equilibrist.*

Nyst. R. 26 sec., L. 24 sec.

P. P.	To R.	R. hand 3.
		L. hand 1.
	To L.	R. hand 1.
		L. hand 3.
Falls		R. normal.
		L. normal.

"*I. B.,*" *tight and slack wire artist.*

Nyst. R. 28 sec., L. 33 sec.

P. P.	To R.	R. hand 2.
		L. hand 2.
	To L.	R. hand 2.
		L. hand 2.
Falls		R. normal.
		L. normal.

"*C. G.,*" *balance equilibrist.*

Nyst. R. 25 sec., L. 20 sec.

P. P.	To R.	R. hand 3.
		L. hand 2.
	To L.	R. hand 2.
		L. hand 3.
Falls		R. normal.
		L. normal.

Mrs. "*E. B.,*" *whirling artist.*

Nyst. R. 34 sec., L. 35 sec.

P. P.	To R.	R. hand 3.
		L. hand 3.
	To L.	R. hand 3.
		L. hand 3.
Falls		R. normal.
		L. normal.

"*C. F.,*" *whirling dancer.*

Nyst. R. 29 sec., L. 31 sec.

P. P.	To R.	R. hand 1.
		L. hand 1.
	To L.	R. hand 2.
		L. hand 2.
Falls		R. normal.
		L. normal.

"O.," whirling dancer.

Nyst. R. 27 sec., L. 28 sec.

P. P.	To R.	R. hand 3.
		L. hand 3.
	To L.	R. hand 1.
		L. hand 1.
Falls		R. normal.
		L. normal.

"P. A.," perch act, 20 years old, 13 years experience.

Nyst. R. 31 sec., L. 38 sec.

P. P.	To R.	R. hand 2.
		L. hand 1.
	To L.	R. hand 5.
		L. hand 6.
Falls		R. normal.
		L. normal.

"Mrs. S.," whirling act.

Nyst. R. 31 sec., L. 25 sec.

P. P.	To R.	R. hand 3.
		L. hand 3.
	To L.	R. hand 3.
		L. hand 3.
Falls		R. normal.
		L. normal.

"E. M.," head balancer, 41 years old, 20 years' experience.

Nyst. R. 34 sec., L. 31 sec.

P. P.	To R.	R. hand 3.
		L. hand 2.
	To L.	R. hand 3.
		L. hand 4.
Falls		R. normal.
		L. normal.

"C. A.," perch act, 28 years old, 13 years experience.

Nyst. R. 21 sec., L. 24 sec.

P. P.	To R.	R. hand 1.
		L. hand 1.
	To L.	R. hand 2.
		L. hand 3.
Falls		R. normal.
		L. normal.

"Mrs. H.," whirling act.

Nyst. R. 22 sec., L. 24 sec.

P. P.	To R.	R. hand 2.
		L. hand 2.
	To L.	R. hand 1.
		L. hand 1.
Falls		R. normal.
		L. normal.

CONVERSATION WITH "G" AND "B," PROFESSIONAL BALLET DANCERS.

"Very little dizziness even when learning, but individual variation; conquest of dizziness depends upon acquisition of ability to jerk head as dancer revolves. Revolving with head not jerking, eyes open or shut, causes dizziness. Refused to revolve jerking head with eyes shut, because it would be sure to cause dizziness and nausea; they were sure it was much worse."

"Mrs. S.," aerial flying trapeze, 50 years old, 30 years in circus.

Nyst. R. 17 sec., L. 18 sec.

P. P.	To R.	R. hand 3.
		L. hand 2.
	To L.	R. hand 2.
		L. hand 3.
Falls		R. normal.
		L. normal.

"L. M.," head balancer, 18 years old, 8 or 9 years experience.

Nyst. R. 37 sec., L. 30 sec.

P. P.	To R.	R. hand 3.
		L. hand 2.
	To L.	R. hand 2.
		L. hand 4.
Falls		R. normal.
		L. normal.

Cases "A" and "B" were tight-rope walkers.

"A."

Nyst. R. 26 sec., L. 26 sec.

P. P.	To R.	R. hand 3.
		L. hand 3.
	To L.	R. hand 3.
		L. hand 3.
Falls		R. normal.
		L. normal.

"B."

Nyst. R. 26 sec., L. 26 sec.

P. P.	To R.	R. hand 3.
		L. hand 3.
	To L.	R. hand 3.
		L. hand 3.
Falls		R. normal.
		L. normal.

Cases "C," "D," "E," and "F" were motordrome whirling racers.

"C," 26 years old, 6 years' experience.

Nyst. R. 22 sec., L. 24 sec.

P. P.	To R.	R. hand 3.	
		L. hand 3.	
	To L.	R. hand 3.	
		L. hand 3.	
Falls	R. normal.		
	L. normal.		

"D," 23 years old, 5 years' experience.

Nyst. R. 26 sec., L. 26 sec.

P. P.	To R.	R. hand 3.	
		L. hand 3.	
	To L.	R. hand 3.	
		L. hand 3.	
Falls	R. normal.		
	L. normal.		

"E," 26 years old, 6 years' experience.

Nyst. R. 26 sec., L. 26 sec.

P. P.	To R.	R. hand 3.	
		L. hand 3.	
	To L.	R. hand 3.	
		L. hand 3.	
Falls	R. normal.		
	L. normal.		

"F," 24 years old.

Nyst. R. 8 sec., L. 8 sec.

P. P.	To R.	R. hand T.	
		L. hand T.	
	To L.	R. hand T.	
		L. hand T.	
Falls	Falling absent.		
	Falling absent.		

Applicant "F" was a vigorous, robust young man and from all appearances the most promising applicant of the day. The caloric test was given 68° douche in both right and left ears with same subnormal reaction. This man had formerly ridden a motorcycle at the rate of 50 miles per hour on circular wall on motordrome and had never experienced nausea or dizziness. A 4+ Wasserman and history of recent chancre explained the reactions.

Many important practical applications may be the outcome of these experiments. It may ultimately become a routine method of accustoming the young pilot to the sensations of the spinning nose dive and the rolling motion of the airship by revolving exercises. Most important of all may be the possibility of teaching the prospective flier the sensations of the loop, tight spiral, and spinning nose dive and how to control himself during the incidental vertigo by daily practice in some such apparatus as that devised by Ruggles.

The most common revolving motions of the aeroplane are the spiral, spinning nose dive, and the roll. In the spinning nose dive, or tight spiral, the aviator may have his horizontal canals or his vertical canals chiefly affected according to the position he assumes. Since every individual is more accustomed to the horizontal canal stimulation than the vertical canal stimulation, it is better that he assume a position in which the horizontal canals are mainly stimulated. In spiral turns, if the aviator sits upright, the horizontal canals are the ones mainly stimulated, and these very slightly, because of the large circular turns. In the spinning nose dive the ship noses vertically down, due to the heavy engine and if the aviator remains in the same upright position as in horizontal flying he will then concentrate stimulation upon his vertical canals. But if he bends forward as the French aviators are instructed to do, he will practically be upside down so that again he will concentrate stimulation upon the horizon-

tal semicircular canals. Physical directors have advised turning movements as practice exercises; but after all this is only of preliminary value, because experienced fliers become so accustomed to turnings and air antics that they, like acrobats, know where they are at all times and are at home in the air.

Space does not permit in this article to quote from the histories of aviators at the disposal of the otologic department cases where, following impairment of the labyrinth due to mumps or syphilis, a man's flying ability has been lost or badly impaired coincidentally with the rapid deterioration of his vestibular sensory acuity. This is additional corroborative evidence of the most convincing nature.

RÉSUMÉ.

General condition of aviator's ears, nose, and throat must be good.

The ground soldier can stand still. The aviator can not. Motion assumes great added importance to the aviator.

Motion-sensing, therefore, assumes great additional importance to the aviator.

Of the senses concerned in motion-sensing, the vestibular sense is the only one whose utility remains constant; hence the necessity of determining the aviator's possession of requisite vestibular sense.

Vestibular tests not only determine functional condition of this portion of the internal ear but give definite information concerning the integrity of parts of the medulla oblongata, pons, cerebrum, and particularly the cerebellum.

It has been determined that up to 18,000 feet there occurs no marked functional change in the vestibular apparatus.

Observations made in an extensive series of blindfold experiments on normal persons, on persons with nonfunctionating vestibular apparatus, on persons lacking hearing only, and on persons with impaired deep sensibilities indicate that perception of motion in a linear direction—

(*a*) During acceleration, is sensed most accurately by those whose vestibular apparatus is functionating;

(*b*) At a sustained rate of speed is sensed accurately by each group except those lacking deep sensibility;

(*c*) During retardation is sensed accurately by those whose vestibular apparatus is functionating;

(*d*) Arrest of motion ensuing upon motion in a linear direction is most accurately detected by the group lacking vestibular function but in possession of unimpaired deep sensibilities.

Experience in aeroplane flights shows that blindfolded normal persons perceive motion changes accurately; that blindfolded persons lacking normal vestibular apparatus do not.

Transitory fatigue may be observed after excessive stimulation of the vestibular end-organs.

Special ability to estimate correctly the degree of falsity of oft-repeated motion-sensing illusions may be developed in normal persons through experience and education. This special ability enables its possessor to maintain safe bodily relation with his environment during the existence of the motion-sensing illusions with which he has become familiar through long experience.

A superficial observation might suggest that possibly the safest aviators would be those lacking vestibular function, such as deaf mutes, inasmuch as they are incapable of developing motion-sensing illusions which, in normal persons, ensue upon spinning nose dives or other whirling aeroplane maneuvers. Possession of normal functionating sensory end-organs always entails the possibilities of subjective sensory illusions, but to argue the advantage of lacking such special sense end-organs is to reach the reductio ad absurdum.

One who shows good responses in the turning-chair shows good detection of movement in the air; one who shows poor responses in the turning-chair shows poor detection of movement in the air. There is this direct relation between the chair and the air and the air and the chair.

THE EAR IN STUNT FLYING.

Crashes that occur during "stunt" flying are usually the result of something having gone wrong with the pilot. Hence it is a pertinent matter for medical investigation. Just what this something is, is not always clear. Poor judgment, a sense of bravado, carelessness, "stunting" at low altitudes, and sudden faintness are among the reasons generally offered in explanation of these accidents. Direct testimony of the pilot is not always available, since many of the crashes result fatally. Neither are pilots who have crashed and survived always able to give a clear and concise account or analysis of the causes of the accident.

Underlying them all, however, there runs a story of momentary loss of faculties, resulting in a manipulation of controls without deliberate judgment. Most accounts of crashes read, "The pilot went into a tail spin and failed to come out." The story of Lieut. J. M. M. is quite typical of those collected by this department.

While flying he went into a tail spin. This produced such overpowering dizziness that, not knowing what he was doing or why, he grabbed the "joy stick" and pushed it forcibly over and threw himself into another tail spin in the opposite direction. Before he could come out of this he crashed.

So many of the accounts of crashes given by pilots who did survive emphasize dizziness (or vertigo), that the organ responsible for dizzi-

force of its momentum. This circulation of the fluid (by momentum) is interpreted by the brain as body movement, but not being in accordance with fact, the body having ceased to revolve, constitutes vertigo or dizziness, and is disturbing to the individual.

Labyrinthine vertigo, therefore, is a false sensation of motion similar to the visual illusion of motion observed when watching a moving train from the window of a stationary coach, both being unavoidable phenomena of normal special sense mechanisms, which, however, the subject easily learns to interpret and disregard.

One must not fall into the error, however, of thinking that the lack of a normal ear mechanism would be advantageous to the flier, because of the immunity of vertigo which this condition would confer. The absence of such an essential organ as a motion-perceiving apparatus is too great a handicap to the man traveling in an "air medium" even to think for a moment that he could dispense with it for the sole benefit of a vertigo immunity, especially since the normal individual can acquire such an immunity without much difficulty.

VERTIGO EFFECTS OF EAR STIMULATION.

1. There are three cardinal planes of vertigo—horizontal, frontal, and sagittal.

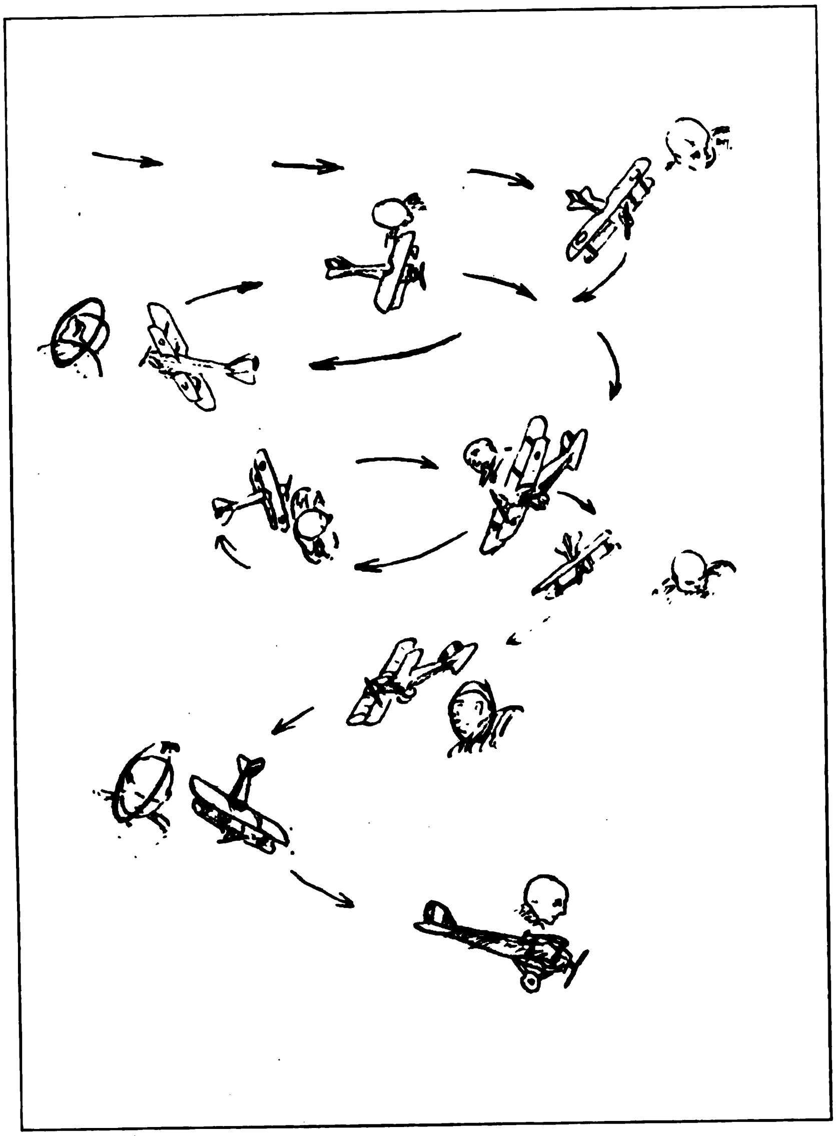
2. A sense of being turned in a horizontal plane—horizontal vertigo—is less disturbing than a sense of being whirled in a vertical plane—vertical vertigo. Each semicircular canal, if stimulated, produces a vertigo in its own plane. Therefore, with the individual in an upright position, stimulation of the horizontal canal is much less disturbing than stimulation of the vertical canals.

3. When a disturbing or disabling vertigo is induced in the vertical semicircular canals the effect can be greatly ameliorated by bringing the vertical canals in a horizontal position or plane, which can readily be done by bringing the head forward.

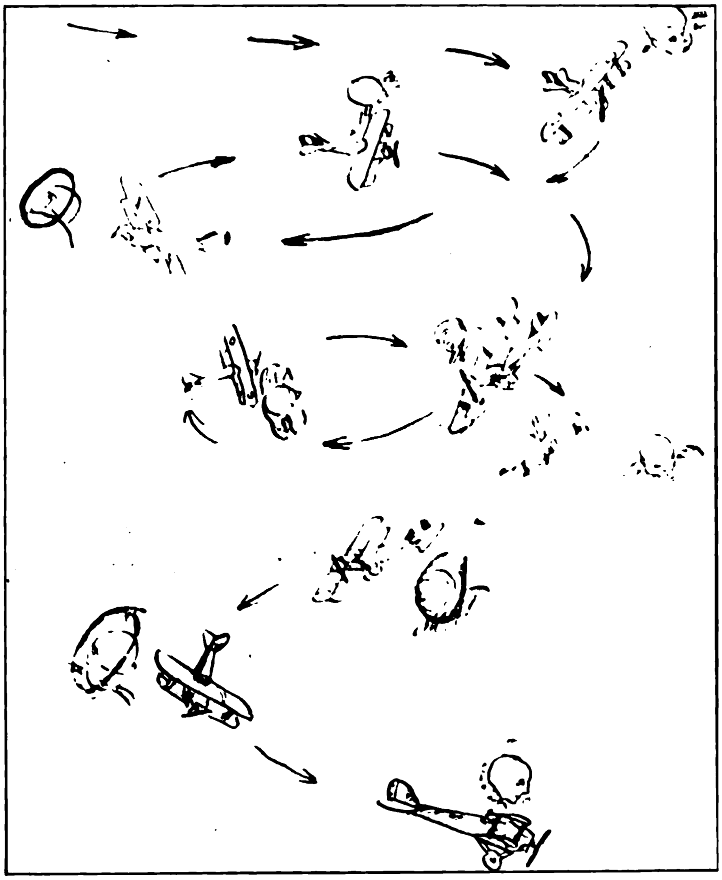
4. All types of vertigo, no matter how induced, are made less and less disturbing by continual repetition.

PRACTICAL APPLICATION OF VERTIGO STUDY TO STUNT FLYING.

Let us consider how the knowledge of the various effects of vertigo gained in the laboratory can be correlated and applied to various stunts.

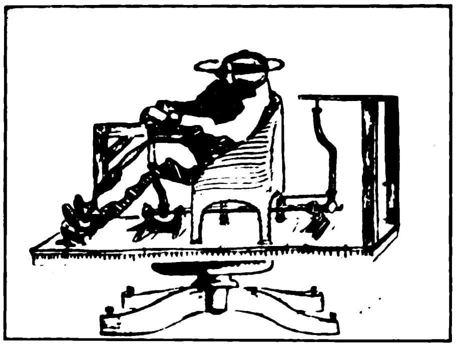


TIGHT SPIRAL.

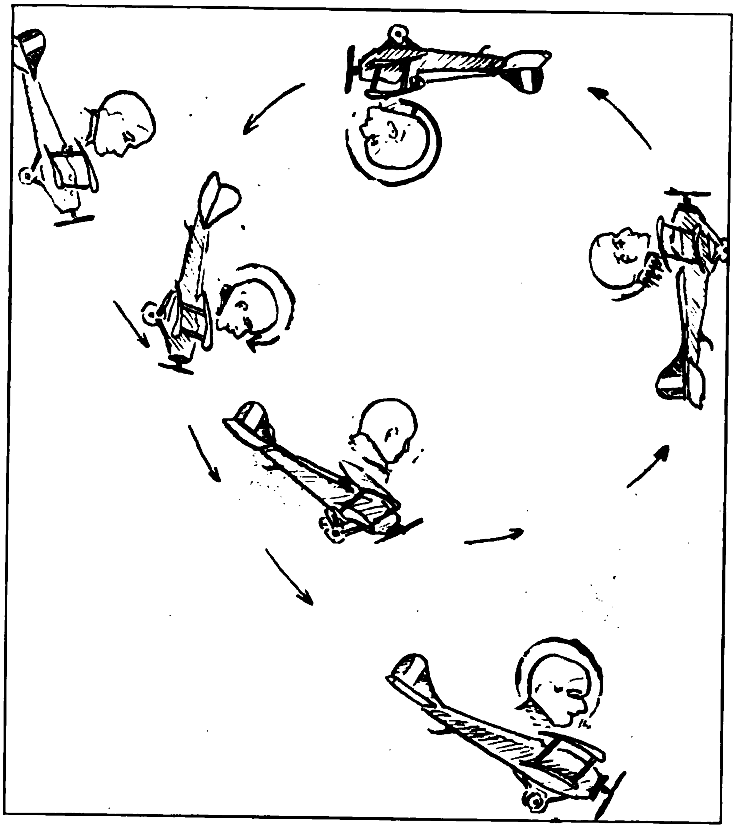


TIGHT SPIRAL.

TIGHT SPIRAL.

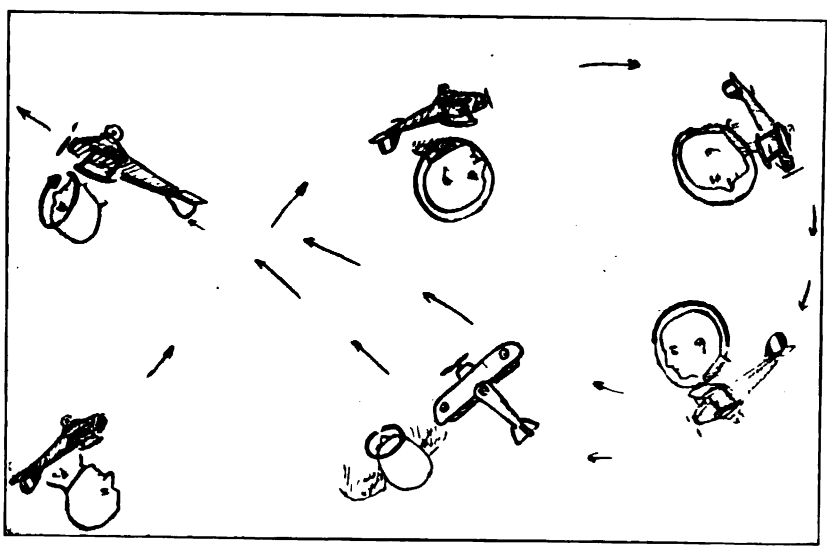


TIGHT SPIRAL.



" LOOPING."

Arrow indicates plane of vertigo.



" LOOPING."

Circles indicate plane of vertigo—sagittal first, then frontal.

SPINNING NOSE DIVE.

In this maneuver the aviator, face downward, is whirled about an axis with his head and body practically parallel to the ground, as shown in the accompanying sketch. In this position there is a stimulation of the vertical semicircular canals in a frontal plane, corresponding to turning in the chair in the position shown below.

When he "comes out" of the spin, the plane of vertigo, which until now has been parallel to the ground, becomes vertical in a frontal plane, i. e., from side to side, so that instead of feeling that he is turning horizontally, he feels that he is whirled in an up and down plane; this being very disturbing, he is apt to lose himself momentarily and attempt to correct this illusionary movement and so throw himself into another spinning nose dive in the opposite direction. When this same experiment is carried out in the chair, i. e., when he is turned with his head forward, simulating his position during this spinning nose dive, and attempts to sit erect, he similarly changes his horizontal vertigo, with which he started, into a sensation of whirling in an up and down plane. In attempting to correct this false impression he throws his body to one side with such violence that unless caught by the examiner he would fall to the floor. It is easy to imagine what havoc would be raised with the controls of an airship under similar conditions. The obvious remedy in both cases is to keep the head down, as it was in the beginning, so that the vertigo remains in the horizontal plane.

TIGHT SPIRAL.

In this maneuver the aviator is whirled about an axis with his head and body practically parallel with the ground but facing the horizon. The stimulation occurs in the vertical canals but in a plane practically parallel with the ground as long as the spiral lasts. When he comes out, however, the plane of vertigo, horizontal until now, becomes vertical in a sagittal (from before backward) plane, so that he feels himself pitching forward or backward and may again meet with disaster in attempting to correct for this illusion.

In the turning-chair this maneuver can be simulated by turning the individual with his head sharply inclined over the shoulder as illustrated.

The obvious remedy for the aviator in this case is to tilt his head sharply to one side when coming out of the spiral, since by so doing he will prevent the vertigo from assuming an up and down whirl.

LOOP.

In this stunt, as shown in the accompanying sketch, the vertical canals are stimulated in the sagittal plane (as in the spiral, but to a lesser degree). The correction is accomplished by tilting the head sharply over one shoulder.

IMMELMANN TURN.

In this evolution, as shown in the foregoing sketches, we have a compound maneuver. During the first or loop portion the vertical canals are stimulated in the sagittal plane, followed in the second part of the stunt by a stimulation of the vertical canals in the frontal plane. The effect of the first portion is lost during the remainder of the stunt so that on emerging the aviator has only to deal with the vertigo induced by the last part, namely vertigo in the frontal plane. The obvious correction is to throw the head forward while " coming out." In a similar manner the vertigo induced by the " barrel roll," " falling leaf," " wing over," and other stunts can be readily analyzed.

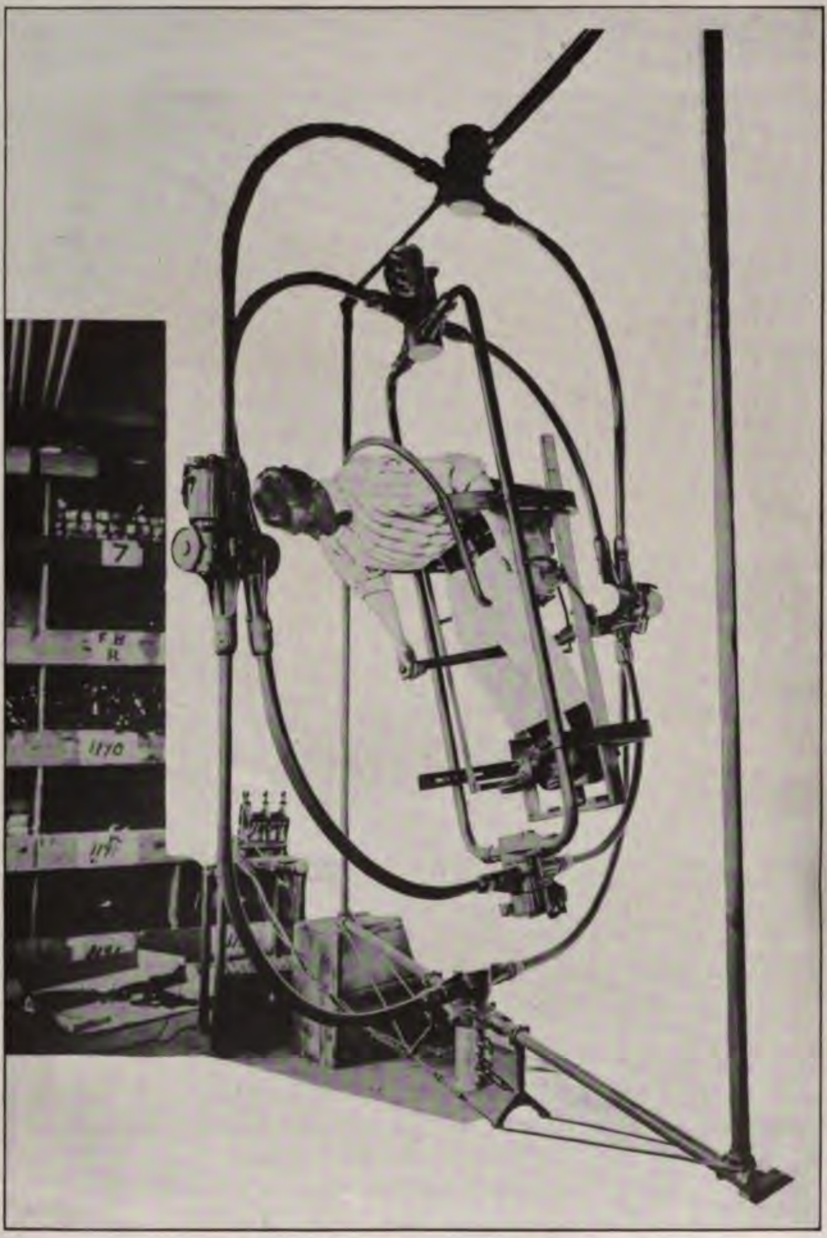
It is, of course, true that the experienced stunt flier is not, as a rule, upset by the vertigo induced by these stunts because of the many hours of practice he has had, but no matter how well trained and experienced he may be he may occasionally find himself, especially in actual combat, doing more whirling and at a greater rate of speed than his training has prepared him for, and an understanding of these principles might be the means of saving his life. As a matter of fact, stunt fliers develop instinctively certain maneuvers which neutralize the disabling effects of vertigo; thus one flier found by practical experience that by leaning as far forward as possible, so that his head was practically inverted, a spinning nose dive gave him practically no disabling vertigo. Another found that going into a straight nose dive immediately following a spinning nose dive saved him from any uncomfortable dizziness.

These fliers have instinctively adopted means which at all times kept the vertigo in a horizontal plane—procedures based on sound otologic principles. Experienced aviators, on being put through the various stunts in the laboratory, when shown how easily the effects of vertigo are neutralized by certain changes in the position of the head, are of the unanimous opinion that such knowledge is of the greatest practical value, especially in stunting. It is obvious that to the less experienced this knowledge is of even greater importance.

The greatest usefulness of the knowledge that "stunting" is an ear problem lies in the fact that the flier may be educated to disregard the vertigo effects of his stunts in the laboratory instead of among the clouds, and without danger, acquire a tolerance to evolutions to a degree impossible in the air. This can be accomplished by the use of an otologic apparatus known as the Orientator. In its construction it is like the cockpit of an aeroplane suspended in concentric rings after the manner of a ship's compass. The movements (or changes of position) which are possible in all directions except actual forward progression are governed by the individual seated in the machine using a set of controls resembling those of an

" RUGGLES ORIENTATOR."

(Supplied through the courtesy of the Naval Consulting Board.)



"RUGGLES ORIENTATOR."

(Supplied through the courtesy of the Naval Consulting Board.)

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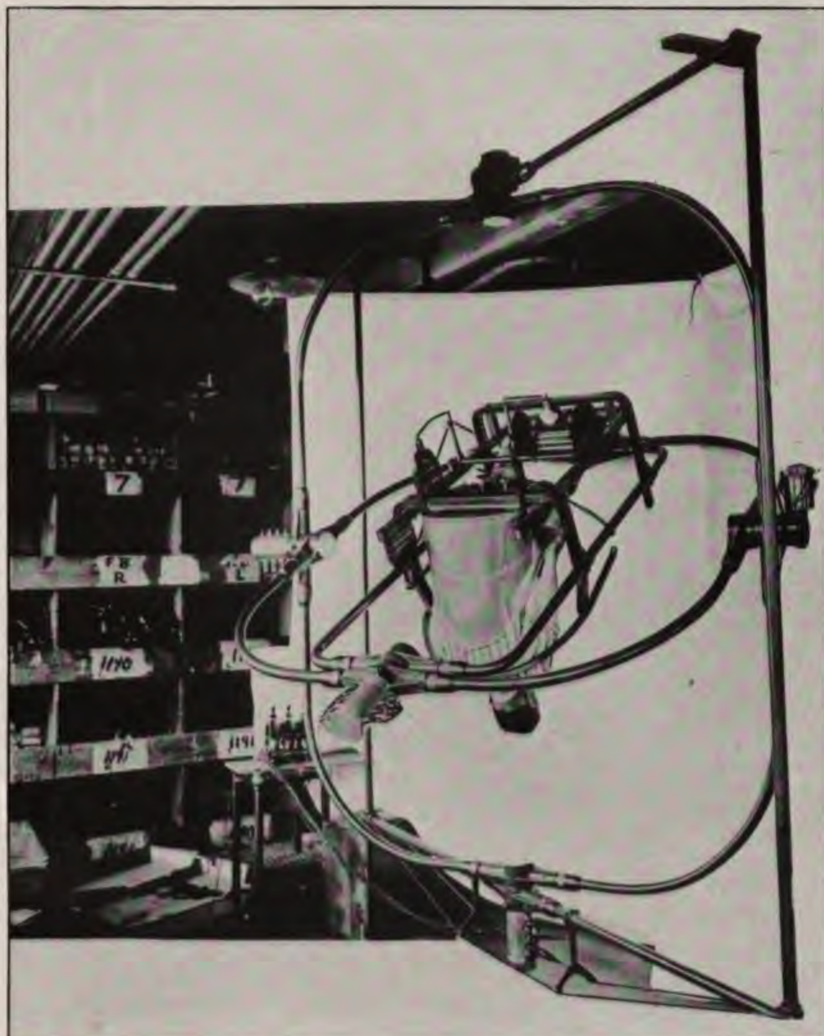

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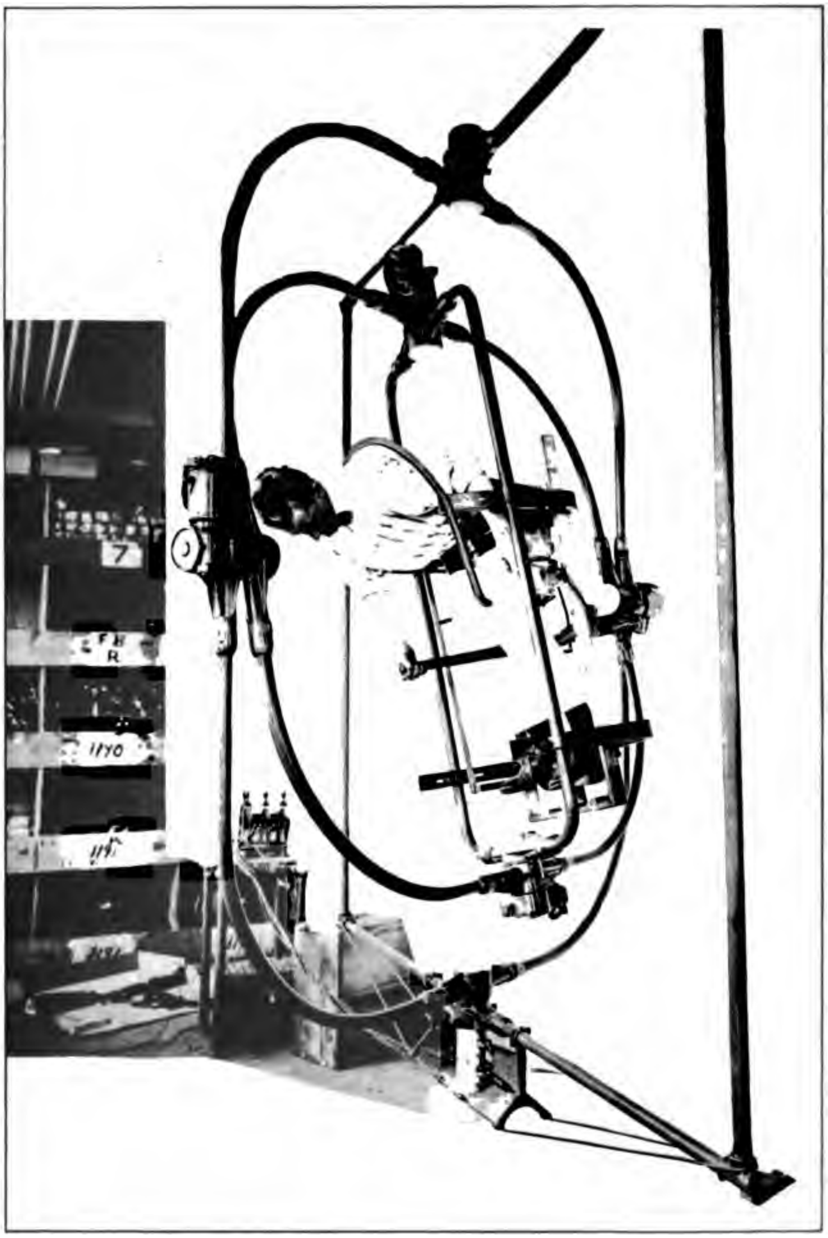

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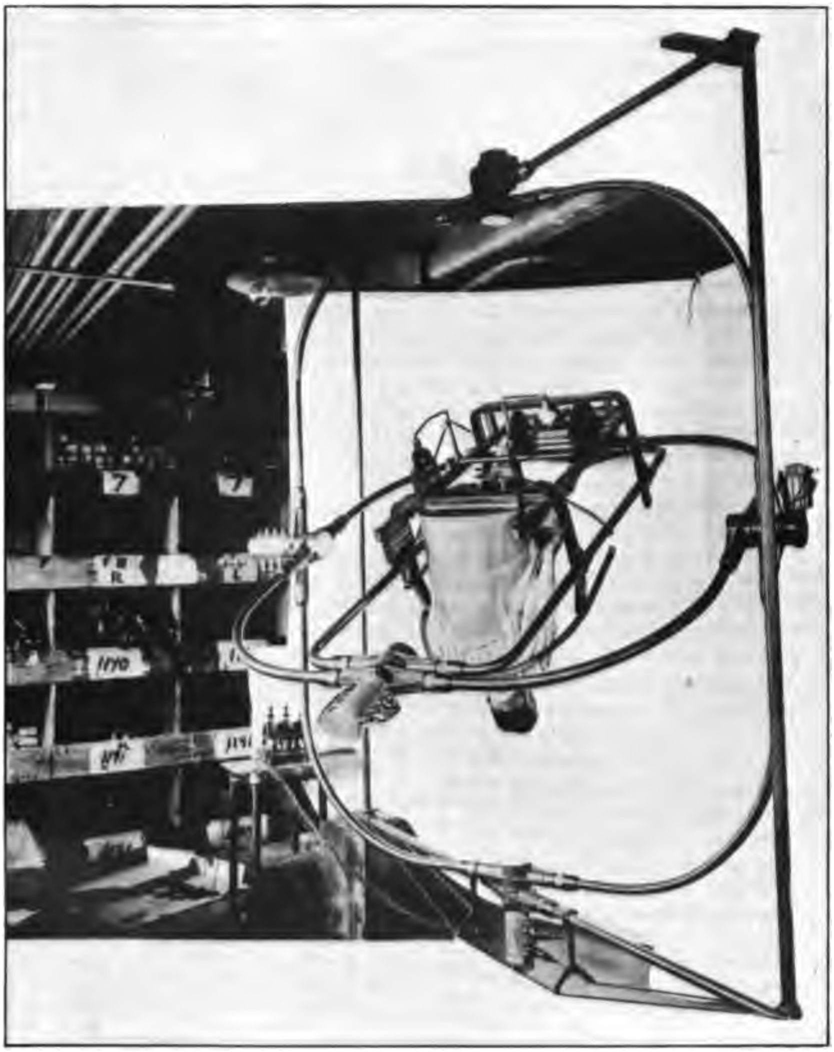

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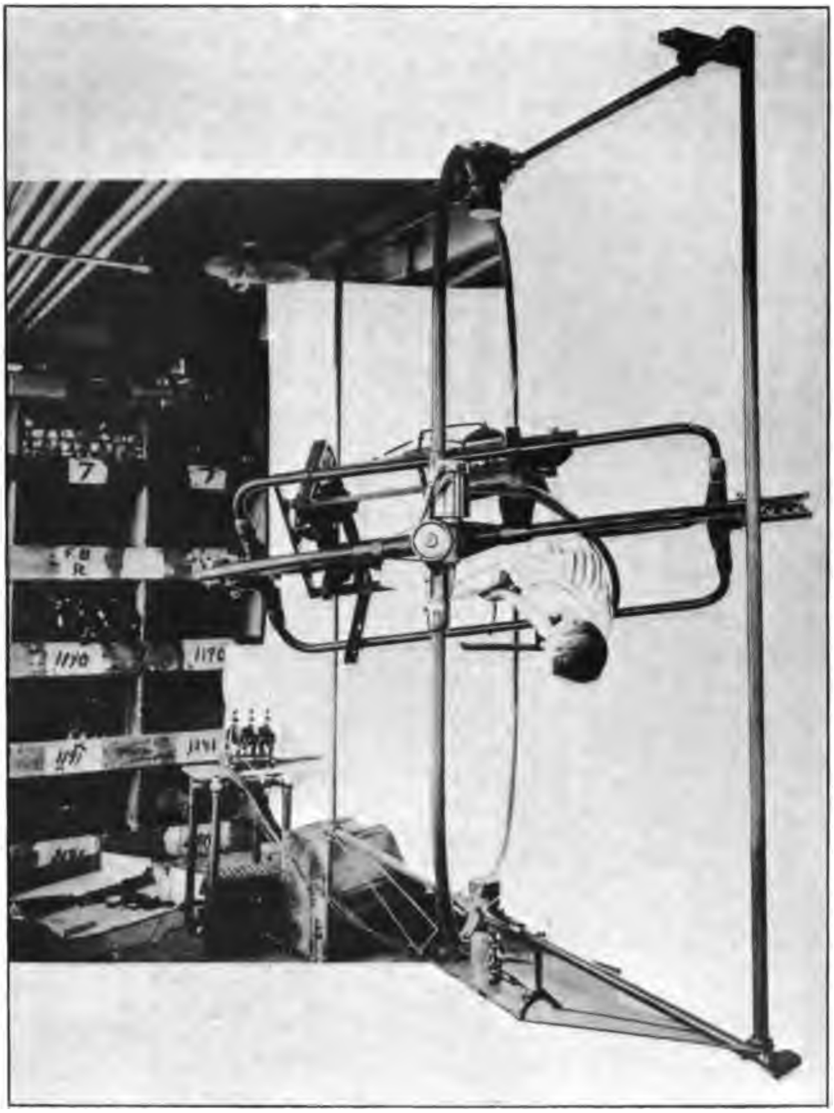

" RUGGLES ORIENTATOR."

(Supplied through the courtesy of the Naval Consulting Board.)

"RUGGLES ORIENTATOR."

(Supplied through the courtesy of the Naval Consulting Board.)

aeroplane. Strapped in this machine he is enabled to execute any evolution, such as the loop, spiral, etc., at any desired rate of speed for any number of turns and thus acquire in absolute safety a tolerance for the disturbing effects of vertigo induced by these evolutions instead of acquiring this tolerance and knowledge by actual flying with its consequent crashes and possible loss of life. In addition, it will enable him to adapt himself to new and most unusual conditions. He will learn to orientate himself in new and rapidly changing positions of the body and to perform properly the complicated acts necessary to control an aeroplane while flying with his head down, etc., which entails an entirely reversed relation to external objects, a condition in itself most disturbing and pregnant with possibilities of disaster.

The orientator placed in the ground- and flying- schools will save many lives and machines, shorten materially the time of flying instruction, and develop a large number of stunt fliers.

V.—THE MANUAL OF THE OPHTHALMOLOGICAL DEPARTMENT RESEARCH LABORATORY.

THE SELECTION OF THE AVIATOR.

In answer to the first call for fliers approximately 100,000 men, the pick of the youth of this country, applied for service in the Aviation Section, Signal Corps, United States Army. Due to the genius for organization and tireless energy of the medical officers of the Regular Army, these men were carefully examined by 500 physicians, working in 67 examining units, and a sufficient number were selected.

It is safe to say that these men, by reason of this careful method of selection, are physically fit, and it is well that this is the case, for an aviator must not only be physically perfect to begin with, but also be kept in training. It is certainly more important to have an aviator in perfect physical condition than a football player. Every flier should be under the care of a medical man thoroughly trained in the care of the aviator and the symptoms and dangers of the lack of oxygen.

If we study for a moment the routine employed in the examination of the eye we will easily see that any man who could pass these tests must have eyes as nearly perfect as nature permits.

PHYSICAL EXAMINATION OF APPLICANTS FOR DETAIL IN THE DEPARTMENT OF MILITARY AERONAUTICS.

I. *History.*—Question the candidate carefully concerning previous or present eye trouble, use of glasses, lachrymation, photophobia, and diplopia. If glasses are worn, symptoms when not wearing correcting lenses.

II. *Stereoscopic vision.*—The ability to appreciate depth and distances by means of binocular vision. The ordinary stereoscope may be used. The cards should be clean and flat. The candidate should have a good light coming over the shoulder directly on the card. The card should be moved back and forth until the point of greatest distinctness is attained. Have the candidate name the sequence of objects from before backward, as he sees them through the stereoscope. This should be done readily and without error, keeping in mind the fact that even though the usual order of seeing the objects on the original card is 9–1–7, 3–2–4, 5–6–8, and 10, the confusion of 4 and 5, 9 and 1, and 8 and 10 occurs in people with normal stereoscopic vision. In case of doubt, use in addition the smaller objects on individual pictures, e. g., on No. 9 from before backward is seen cross, balloon, and flag; No. 8, balloon, cross, rod, and pennant; No. 10, pennant, balloon, and cross. Inability to stereoscope properly is a cause for rejection.

III. *Ocular movements.*—These are tested roughly by requiring both eyes of the candidate to be fixed on the examiner's finger, which is carried from directly in front of the eyes to the right, to the left, up and down. The ocular movements must be regular and identical.

IV. *Pupillary reactions.*—These should be regular and equal when responding to (1) direct, (2) indirect light stimulation, and (3) to accommodation. Face the candidate, who should be looking into the distance, and place a card as a screen before both eyes. Uncover one eye after a short interval and allow bright daylight to shine into this eye. The resulting contraction of the iris of this eye is called a direct reaction. Repeat the test, but now observe the iris of the shaded eye. If this iris contracts, it is termed the indirect or consensual reaction. Repeat tests on the other eye. With both the candidate's eyes open and uncovered, have him fix on a distant object, then focus on a pencil point held approximately 10 centimeters in front of the eyes. Both irides should contract, which is called the reaction to accommodation.

V. *External ocular examination.*—Place the candidate facing a good light and examine each eye carefully with the aid of a hand lens, noting any abnormality. The eye should be free from disease, congenital or acquired, such as lesions of the cornea, iris, or lens, including affections of the surrounding structures, such as pathological conditions of the lachrymal apparatus, conjunctival deformities, or any affection which would tend to cause blurring of vision if the eyes, unprotected by glasses, were exposed to wind or other unfavorable atmospheric conditions.

VI. *Ocular nystagmus.*—If it occurs on looking straight ahead or laterally, 40° or less, it is a cause for rejection.


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O T C L

(*a*) Spontaneous ocular nystagmus produced by extreme lateral rotation of the eyes, 50° or more, is not a cause for rejection, as it is found in the normal individual. It is usually manifested by a few oscillating movements, never rotary, which appear when the eyes are first fixed in extreme lateral positions. Select a scleral vessel near the corneal margin as a point for observation.

VII. *Field of vision.*—The confrontation test may be used to determine roughly the limits of the visual field. The field is tested separately for each eye. Place the candidate with his back to the source of light and have him fix the eye under examination (the other eye being covered) upon the examiner's, which is directly opposite at a distance of 2 feet. For example: The candidate's right eye being fixed upon the examiner's left eye; the examiner then moves his fingers in various directions in a plane midway between himself and the candidate, until the limits of indirect vision are reached. The examiner thus compares the candidate's field of vision to his own, and can thus roughly estimate whether normal or not. A restricted field of vision or marked scotoma should be confirmed by the use of a perimeter, as it would be a cause for rejection.

VIII. *Color vision.*—Should be normal. A Jennings test is required. If confusion, the eyes should be tested with a Williams lantern. The Jennings blank, properly filled out, should form a part of the physical record. If the candidate is suspected of having learned the Jennings test, the card and blank may be turned over and punched from the unfinished side.

IX. *Muscle balance at 20 feet.*—A phorometer, with spirit level or maddox rod and rotary prism attached, should be used. Muscle balance is satisfactory, provided there is not more than 1 degree of hyperphoria, 2 degrees of exophoria, or 6 degrees of esophoria (if in this latter case there is a prism divergence or abduction of not less than 6 degrees). In all cases of heterophoria the duction power of the muscles must be taken and recorded.

(*a*) The screen and parallax test: In case the above-described apparatus is not available, the following method may be used until the proper instruments are obtained:

The candidate is seated 6 meters from a 5-millimeter light on a black field or a 1 centimeter black dot on a white field, which he fixes intently. Shift a small card quickly from eye to eye and note any movement of the eye as it is uncovered and ask the candidate to describe any movement of the eye or the light. Orthophoria obtains if there is no apparent movement of the eye or the light. Movement of the test object or eye with the card signifies exophoria, against the card, esophoria, and vertical movement hyperphoria. Prisms are placed with the base in for exophoria, out in esophoria and up or

down in hyperphoria, until the test object and the eye just begin to move in the opposite direction. The weakest prism which causes reversal of the movement, minus 2 prism degrees, is the measure of the heterophoria. If there are less than 5 degrees of heterophoria, only 1 prism degree is subtracted.

(*b*) Near point of convergence: A 2-millimeter white-headed pin or a 1-millimeter black dot on a white card is carried toward the subject along a millimeter rule from a distance of 50 centimeters, and the point noted at which one or both eyes cease to fix or diplopia is first noted by the candidate. This point is measured in millimeters from the anterior surface of the cornea. Keep the test object in the mid line, a few degrees below the horizontal plane. A near point greater than 65 millimeters at 25 years of age, and 85 millimeters at 30 years of age is a cause for disqualification.

X. *Visual acuity.*—(*a*) Acuity for distance: Test each eye separately, 20 feet from a well-illuminated card with Snellen letters. Full twenty twentieths vision in each eye is desired, but a candidate may be allowed to miss three letters on the 20/20 line with one eye, provided the other has full 20/20 vision, and all other tests are normal. Visual acuity should be taken without the use of correcting lenses.

Place a plus 2.00D sph. before each eye successively while the other eye is covered. A candidate who can still read 20/20 with either eye is disqualified.

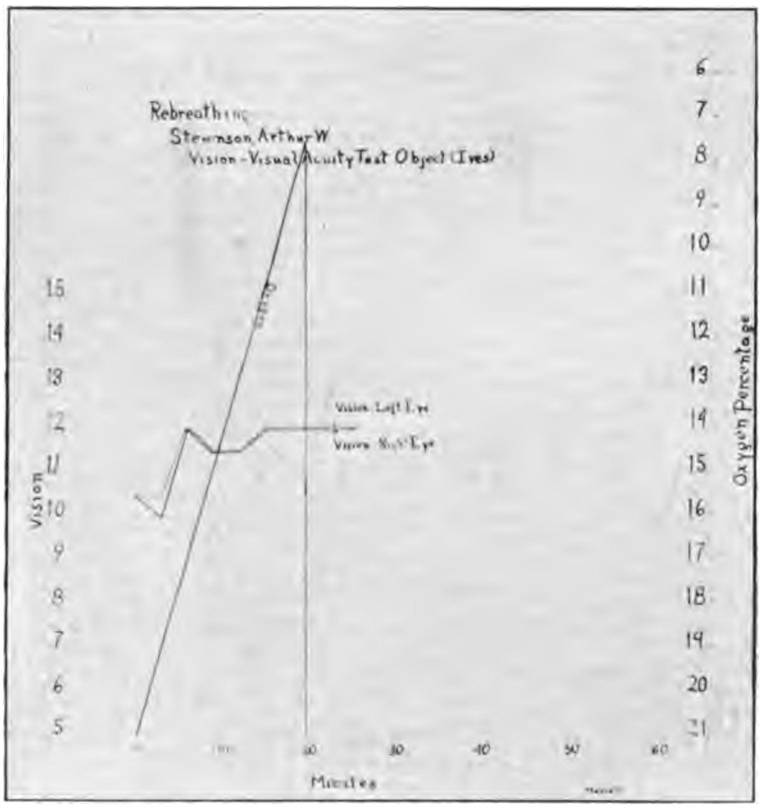
(*b*) Near point, or acuity for near vision is determined separately for each eye by requiring the candidate to read, in a good light, Jaeger test type No. 1, gradually bringing the card toward the uncovered eye until the first blurring of the print is noted.

The distance of this point from the anterior surface of the cornea, measured in centimeters, is the near point. A distance greater than 11 centimeters at 19 years of age, greater than 13 centimeters at 25 years of age, or greater than 15 centimeters at 30 years of age, disqualifies.

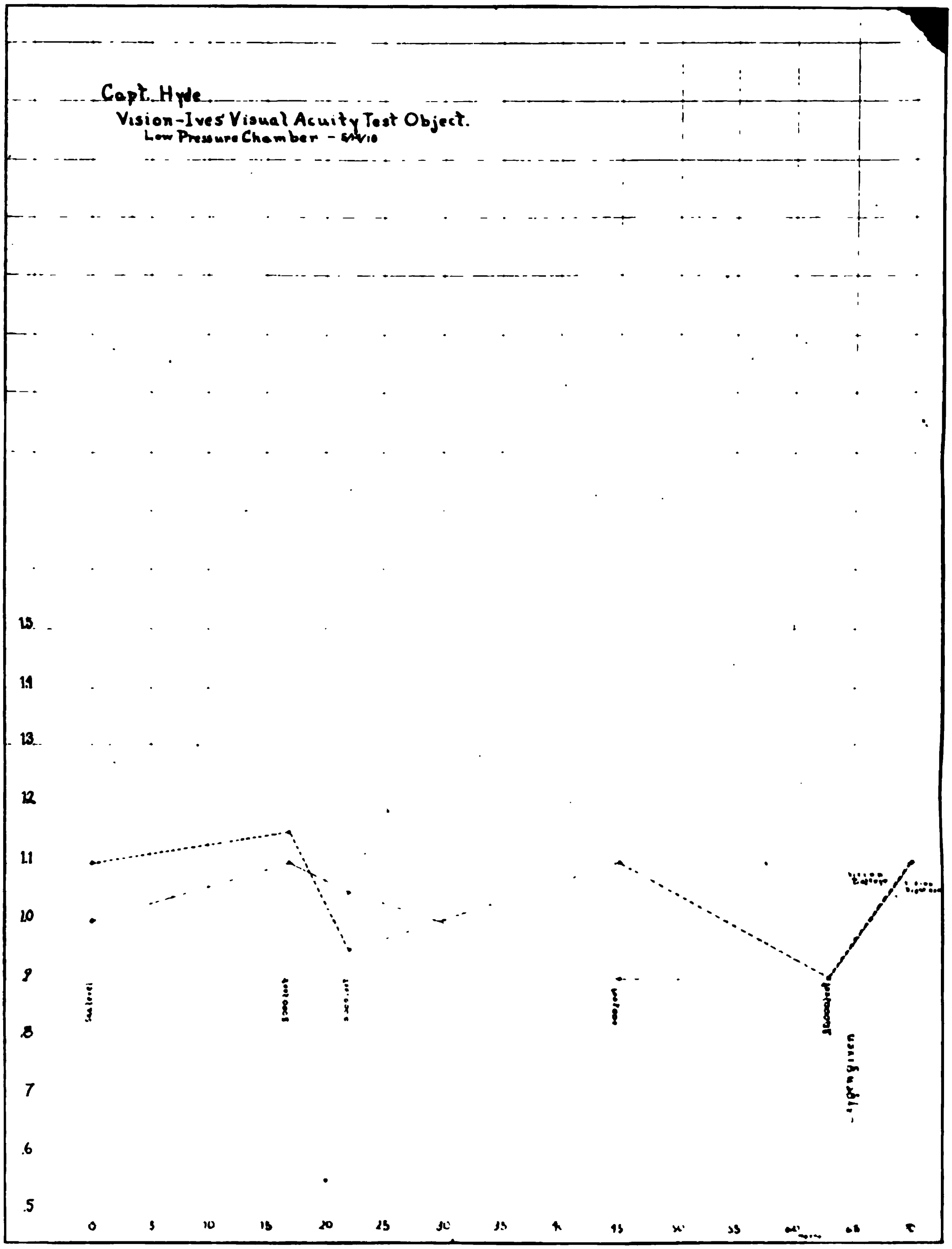
XI. *Ophthalmoscopic findings.*—Drop one drop of a 5 per cent solution of euphthalmin in each eye. Have the candidate keep his eyes closed. After 15 minutes repeat the drops, then examine 15 minutes later. A solution of cocaine, 4 per cent, may be substituted, cautioning the candidate to keep his eyes closed between installations. A pathological condition of the fundus, active or quiescent, is a cause for rejection.

VALUE OF THE EYE IN AVIATION.

I. *Judgment of distance.*—Judgment of distance is assisted by the power of stereoscopic vision, and for this reason the eyes of all candidates for admission into the Aviation Section, Signal Corps



Rebreathing
Stevenson, Arthur W
Vision - Visual Acuity Test Object (Ives)
Vision Left Eye
Vision
Oxygen Percentage
Minutes


Capt. Hyde
Vision-Ives' Visual Acuity Test Object.
Low Pressure Chamber
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70

of the United States Army, have had their binocular vision tested by means of a stereoscope. Inability to stereoscope quickly and accurately is considered a cause for disqualification. We know that if a man loses one eye he is often able to judge distance very accurately with the remaining one, but it requires time for him to develop this power. It would therefore seem logical, at least while we are able to select our men carefully, to accept only those with normal stereoscopic vision.

Speaking of error of judgment in flying as a cause of aeroplane accidents, Anderson states that this error may occur in getting off the ground, in the air, or when landing. Of the 58 crashes in the "V" series, this cause accounted for 42—4 in getting off the ground and 38 in landing.

Of the many examples of error in judgment in flying, perhaps the commonest is when, on landing, the pupil misjudges his distance from the ground and either flattens out too soon and "pancakes," with a possible crash, depending on the height, or else flattens out too late and strikes the ground at a great angle, usually overturning and wrecking the machine.

It is difficult to estimate and account for these errors of judgment. In some cases it may be due to insufficient instruction. In other cases, even after prolonged instruction, the pupil may still misjudge distance, and on examination one occasionally finds that his standard of vision is below normal; but, on the other hand, he may be found physically fit, with normal vision and normal muscle balance. In the latter case Anderson believes it may be a question of delayed reaction time, and especially the visual reaction time, upon which the aviator is so much dependent. Normally this reaction time is nineteen one-hundredths or twenty one-hundredths of a second. It may be delayed by fatigue and excesses, but in some individuals who are otherwise physically fit it is found to be much slower than in others.

Hence, in the selecting of candidates for aviation the visual and other reaction times should be normal. By the French medical authorities on aviation candidates are rejected if simple reaction times are found to be of the delayed type. The Italians also seem to lay considerable stress upon simple reaction time. The men who have done the most work in reaction time in this country, are of the opinion that simple reaction time is of little value in the selection of candidates for aviation. The accurate determination of the visual discrimination reaction time and other complex reaction times might be of considerable value. It would seem as though physical condition on a given day and the added strain of low oxygen tension should be taken into consideration in seeking the cause of these accidents. We know that there might be a temporary visual disturbance or weaken-

ing of the external ocular muscles, and this might account for some of the accidents. Naturally, examination of the eyes later on might show nothing.

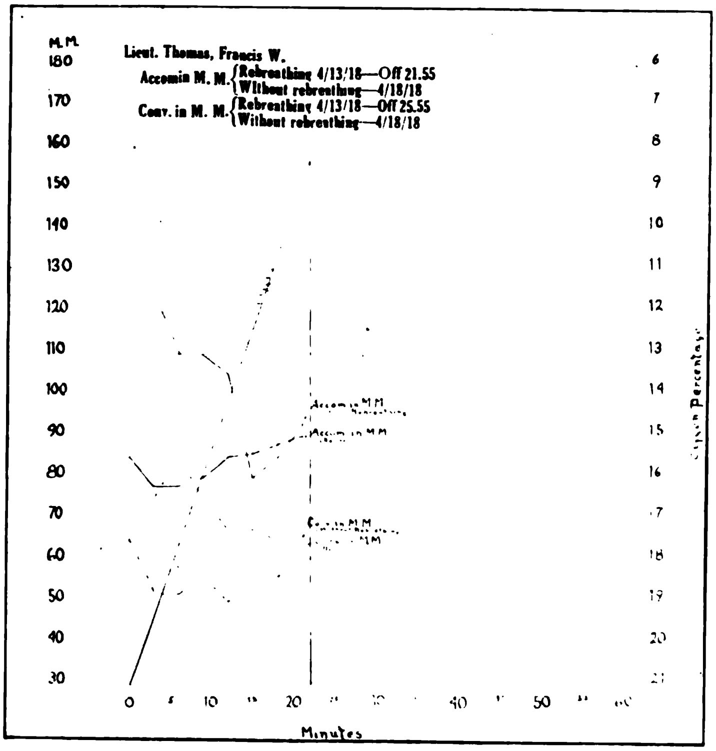
II. *Normal visual acuity.*—As long as we can in this country select only those men with practically perfect vision it would seem well to do this. A man with poor vision will not be able to see an enemy plane as soon as a man with perfect vision. He will not be able to accurately differentiate objects seen from the air in selecting a landing place, and when he has reached the ground he will not see obstructions in his path as clearly as he should. The latter may result in the plane being "nosed over." In a recent discussion of the "Physical Qualities of Aviators" all the British officers and physicians taking part agreed that the factor of vision was of the greatest importance, and Clark pled for the use of a cycloplegic in making examinations for admission to the flying corps. During the low oxygen tension test visual acuity diminished in 28 per cent of the normal men examined and in 37.5 per cent of the men who were ocularly disqualified for flying.

III. *Normal color vision.*—It is important that the flier have normal color vision in order that he may accurately determine the markings of the different planes, differentiate between signal lights, and in helping him to make landings at night. During the day the discrimination between the color of a building, field, forest, or swamp is essential in selecting a landing place. There has been no change in color vision during the rebreathing test or in the low-pressure chamber.

IV. *Field of binocular fixation.*—It is important that the aviator be able to carry the eyes as far as possible in various directions without turning his head and without seeing double. If a man has a contracted binocular field of vision, it certainly impairs his efficiency, whether observing, fighting, or flying. In 50 per cent of the subnormal men examined during the low oxygen tension test we have found contraction of the field of binocular fixation, the contraction being most marked in the upper field.

V. *Muscle balance.*—Normal muscle balance should be insisted upon, for even a small defect may be accentuated by the strain of flying and lack of oxygen and result in diplopia or at least a marked contraction of the field of binocular vision at low altitudes. Exophoria and hyperphoria have been shown to be the most important, due to the fact that the weakness of the ocular muscles caused by the lack of oxygen produces diplopia more readily in exophoria and hyperphoria than in esophoria.

VI. *Field of vision.*—The field of vision should be normal, as the aviator's safety depends to a great extent upon his ability to detect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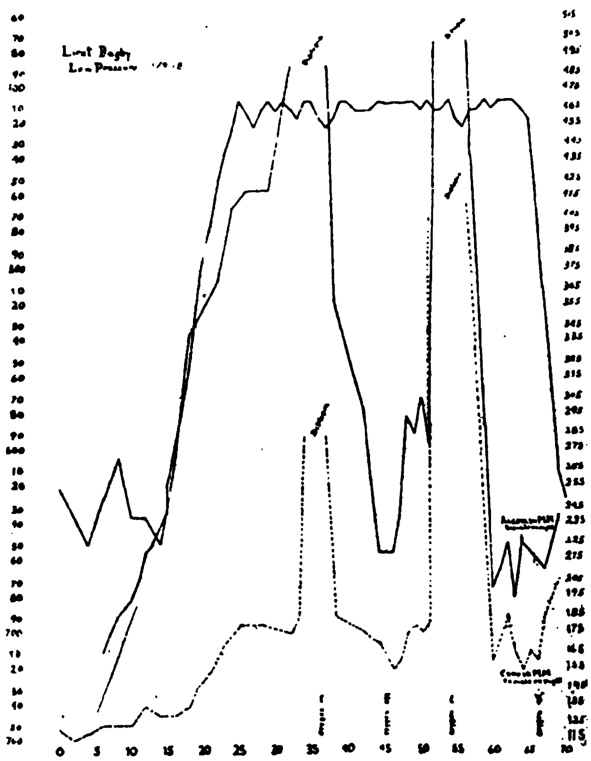
Minutes

enemy planes or in training his own plane in the various fields while his gaze is fixed straight ahead. The aeroplane and the goggle also do harm in that they restrict the field of vision, and many accidents result from this. Everything should be done to improve the construction of goggles and planes so that the visual field will be restricted as little as possible.

VII. *The perception of motion and its direction.*—The perception of motion and its direction is of great importance to the aviator. Appropriate tests for measuring this have been devised. The best pilots say that they finally develop the power to use the periphery of the retina so that it is of greater value in detecting enemy planes.



VIII. *The importance of the eye in maintaining equilibrium.*—Before going into this, first let it be stated that the subject of equilibration is a complex one and that those of us who have an interest in it from a practical standpoint appreciate the difficulty of the subject and realize that although the aviator may fly when one part of this mechanism is deranged or destroyed, we believe that in selecting men for flying positions that it is well to make sure that all the senses used in this complex act are normal. The most important factors in receiving impressions are deep sensibility, tactile sense, the

vestibular apparatus, and the eyes. The central nervous system connections must functionate perfectly to use the information it receives to the best advantage. Finally, the muscles should be in condition to carry out the commands of the central nervous system.

That many aviators depend largely upon their visual impressions in the maintenance of equilibrium is evidenced by the fact that they often tie a piece of string as a streamer to one of the forward struts, so that they may more readily note the first evidence of a side slip when they are flying in a cloud. In spite of the fact that we miss the visual impressions when they are not received, we are still able to control the plane if the remainder of the balance mechanism is functioning normally.

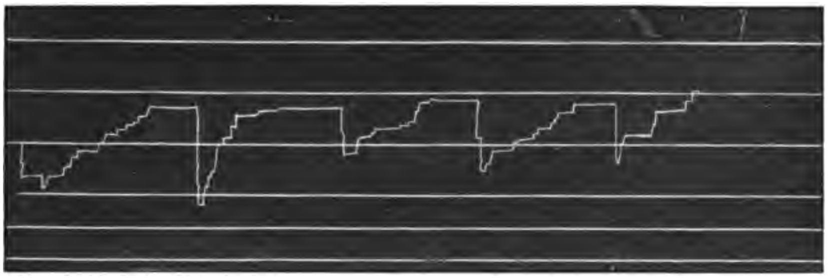
IX. *Retinal sensitivity to light.*—It is important that the retina be sensitive to light impressions, especially for those men who are carrying out night bombing expeditions. With this in mind, most of the allied nations require special tests for retinal sensitivity. A test of the contrast sensitivity of the retina is believed to be the most useful for our work, and only men who have normal sensitivity in this respect will be selected for night flying.

THE CARE OF THE FLIER AND THE EFFECT OF ALTITUDE AND THE STRAIN OF FLYING ON THE EYE.

Even though our aviators have been examined with the greatest care and their eyes are as nearly perfect as nature permits, the adapting mechanism of the human machine, including the eye, was designed for use on earth, and altitude adds an unusual strain. Medical men agree that definite physiologic changes occur in man living at high altitudes which permit them to withstand lack of oxygen, but they believe from the examinations that have been made of fliers that they do not become acclimated, but often show rather rapid physical deterioration.

The most important ocular symptom is failing vision. The pilot complains that he can not see the ground clearly in landing and has difficulty in picking out enemy planes. There may be no defect in vision, but there is usually some slight error which was previously correctable by an unconscious muscular effort. The muscles become fatigued, due to the strain of flying, and the defect shows itself. A few days' rest has been sufficient in the few cases Maj. James L. Birley, R. A. M. C., has seen, to restore normal vision.

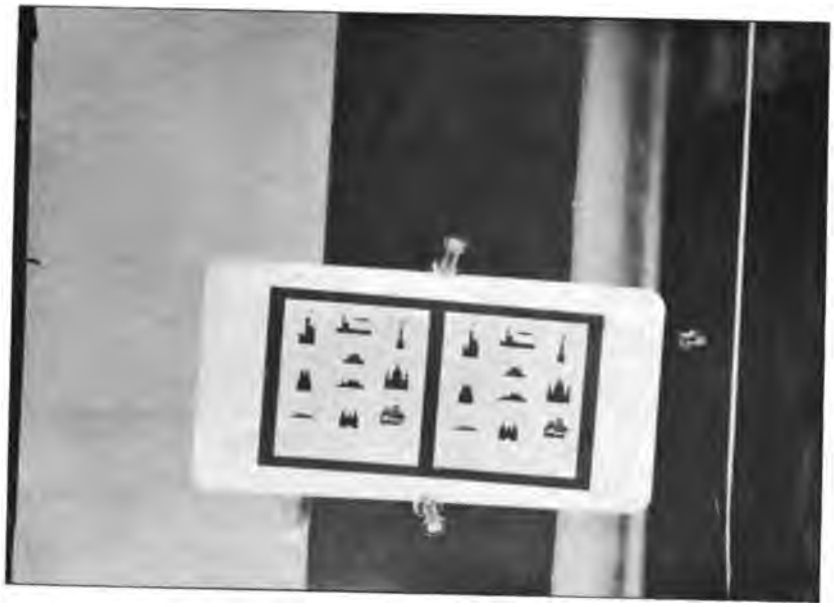
Certain individuals with apparent perfect acuity of vision are ocularly weak in that they are unable to make use of both eyes, due to some defect in binocular vision or fusion sense. This interferes somewhat with judgment of distance, and the disability tends to increase under the strain of aviation and lack of oxygen, resulting in



Lieut. Johnson's visual acuity test with subject on rebreathing apparatus. Oxygen at end of experiment, 10%. Lower parts of curve indicate maximal vision. Subject observes test object for periods of three minutes, with one minute intervals of rest.

Test object observed during periods of three minutes with one minute intervals of rest. Amyl nitrite (2 minims) inhaled during third period. Lower excursions of curve indicate clearer vision.

CADET D. W. MILLS, 5/9/18.



bad landings, "crashes," and consequent loss of personnel and material. These conditions may often be improved by treatment.

Irritation, congestion, and inflammation of the conjunctiva and epiphora were common complaints of the fliers at Chanute Field. Most aviators realize the necessity for wearing goggles, but many of them fit poorly, allowing the cold air to strike the eye with great force, most often near the internal canthus where the lachrymal puncta are situated. This probably accounts for the disagreeable symptoms noted. The remedy is found in the wearing of properly fitted goggles and the use two or three times daily of a 2 per cent boric acid solution containing 1 grain of zinc sulphate to the ounce. In some instances 1 grain of cocaine and 10 to 30 minims of 1-to-1,000 adrenalin chloride may be added to the ounce.

GOGGLES.

I. *The glass*—

(*a*) Should have an optically plane surface.

(*b*) Should have a light transmission of 90 per cent or over for plain white glass.

(*c*) If a colored glass is desired, Noviol "C," made by the Corning Manufacturing Co., of New York, with a light transmission of 87 per cent, is excellent. Euphos has given great comfort and the glass passes a good test. The retina of the eye is sensitive to the glare, and that is probably one of the causes for physical fatigue of the aviator. The colored lenses shut out most of the ultraviolet rays, and some consider them of great value in bright sunlight, in snow, on water, and above the clouds. Many aviators object to any tint in their lenses, due to the fact that they say they are unable to see as well in a fog and that the color in the lenses changes the color of objects looked at, especially the German uniform and the fields in making landings, resulting sometimes in the selection of poor landing places or in the misjudgment of distance.

(*d*) Thickness of the glass: The lenses should be 2 or 3 millimeters thick.

(*e*) Many aviators insist upon some form of so-called nonbreakable glasses, which is nothing more than two pieces of glass with a piece of celluloid between. This piece of celluloid cuts down the transmission of light between 16 and 19 per cent, and no matter how clear the celluloid is originally, it deteriorates with age and becomes yellow and less transparent. When these glasses are struck with considerable force the glass on the posterior surface splinters off and flies into the eye. Even with these disadvantages, some men insist upon the nonbreakable feature, and perhaps not without reason, for even though the splinters do fly off the back of the glass, the eye closes immediately in an accident, and these small particles would

hardly penetrate the lids, and there is no doubt that in some instances the celluloid prevents the driving of large pieces of glass toward the eye.

II. *Visual field.*—It is most important that the aviator have a broad field of vision, and for this reason a large curved glass is desirable. Without a broad field of vision the aviator may not see one of his own planes in time to prevent an accident. Pilots who are doing actual fighting demand a broad visual field above everything else.

III. *Visual acuity.*—It is important that the aviator have keen vision, and for this reason glass with optically plane surfaces should be furnished and a determination made of how much visual acuity is cut down by celluloid.

IV. *Safety to the eye.*—The parts of the goggle which come in contact with the brow, nose, and cheeks should have round edges and be protected by a soft cushion.

V. *Lightness and strength.*—The goggles should be light, so that they will not cause discomfort. They should be simple in construction and yet strongly made.

VI. *Comfort.*—The goggles should not press upon the bridge of the nose so as to produce pain, and the elastic which holds the goggles in place should not be drawn too tight. An adjustable interpupillary distance might be valuable.

VII. *Cleansing.*—Goggles should be easily cleaned, and there should be no place for vermin to hide.

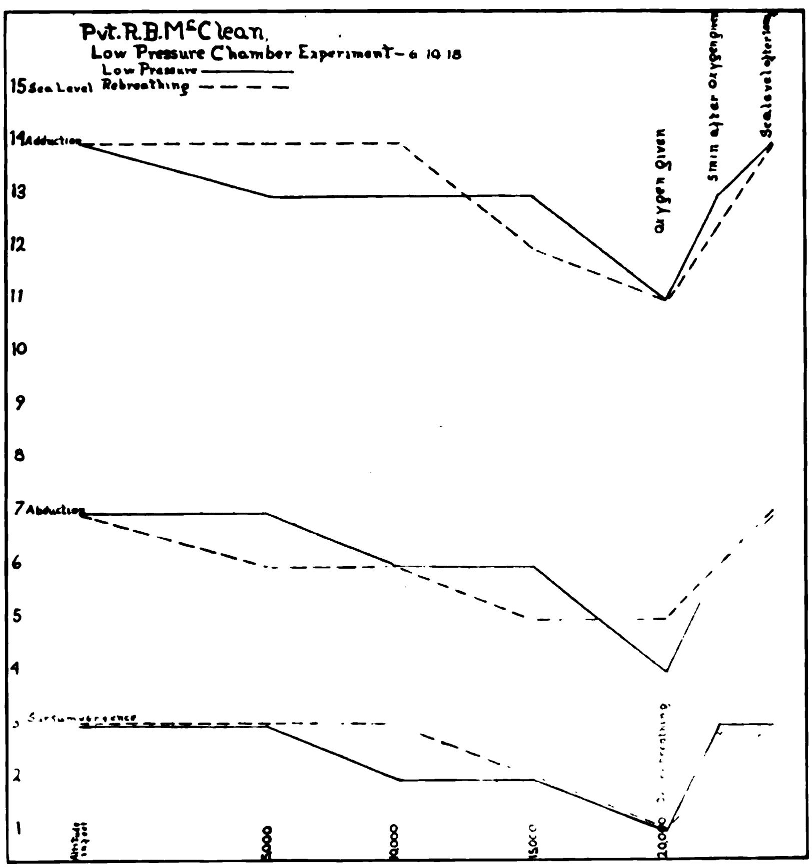
IX. *Protecting sinuses.*—There should be sufficient covering in connection with the goggles to protect the frontal sinus. Aviators often complain of pain in this region when it is left exposed.

X. *Ventilation.*—The goggles should be carefully adjusted so that there are no leaks, especially near the nose, which would permit the wind to strike the internal canthi directly. Most of the aviators who have done fighting at high altitudes believe that the goggles should be equipped with some indirect method of ventilation.

XI. *Material for lenses.*—Glass is best. Celluloid and gelatin smear too easily and celluloid deteriorates too rapidly. Mica chips and cracks.

XII. *Noninflammable.*—The material of which the goggle is composed should be noninflammable and for this reason any wooly material is dangerous, as it burns readily. Incendiary bullets are now being used, and they cause great damage when they strike a gas tank.

XIII. To further prevent injury to the aviator, all parts of the fuselage or control system which he is liable to strike in falling should be protected by pneumatic cushions.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Low Pressure Chamber Experiment – 6 10 18
Low Pressure
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oxygen given
5 min after oxygen given
Sea level after

"Doctors and professional aviators have noticed that during the ascent respirations become more rapid and the heart beats faster up to an altitude of 1,500 meters. At this altitude the vision may become less clear, although a French observer states that at 2,000 meters the visual acuity usually increases by a third by reason of the congestion of all the organs of the head and in particular of the choroid and of the retina." Visual acuity tests carried out under low-oxygen tension on the rebreathing apparatus and in the low-pressure chamber have not shown any marked increase in vision. On the contrary, the improvement, when it occurred, has usually been slight, but more often the vision has remained unchanged and in a few cases has fallen off considerably.

"During the descent, there is another series of phenomena which increases as one approaches the ground. It is first the sensation of smarting of the face with redness and very high color. The eyes sting and are injected. The nostrils are moist and then comes a headache, or more exactly a sort of heavy feeling in the head with a sensation of obstruction. Swelling in the pharynx at the level of the larynx. Finally there is a strong tendency to sleep."

"To explain these difficulties during the descent, one may admit that an airman who falls to the earth in four or five minutes or less, after having attained 3,000 or 4,000 meters of elevation in 20 minutes, had not had time to adapt his circulatory system to the different barometric pressures." From the experimental work done, the change in oxygen tension would seem to be the most important factor in the production of symptoms.

The question of correcting lenses is an important one and most ophthalmologists feel that it is better in principle not to have vision corrected by lenses, at least as long as we are able to obtain men with nearly perfect vision. The aviator needs perfect vision and a normal ability to distinguish colors, a rapid valuation of distances and the faculty of accommodating rapidly. There have been many accidents described as due to hyperopia, myopia, and astigmatism, and it is a question if it would not be well to use a cycloplegic in the examination of all candidates for admission to the flying corps.

The research work done in this laboratory has shown definitely that a flier's life depends, to a great extent, upon his ability to keep in condition, both mentally and physically. Loss of sleep, dissipation, or illness will so lower his resistance that his eyes break more readily under the added strain of low-oxygen tension, which, in actual flying, would frequently result in death.

When every flier understands this fact we will have a more efficient flying corps and fewer accidents.


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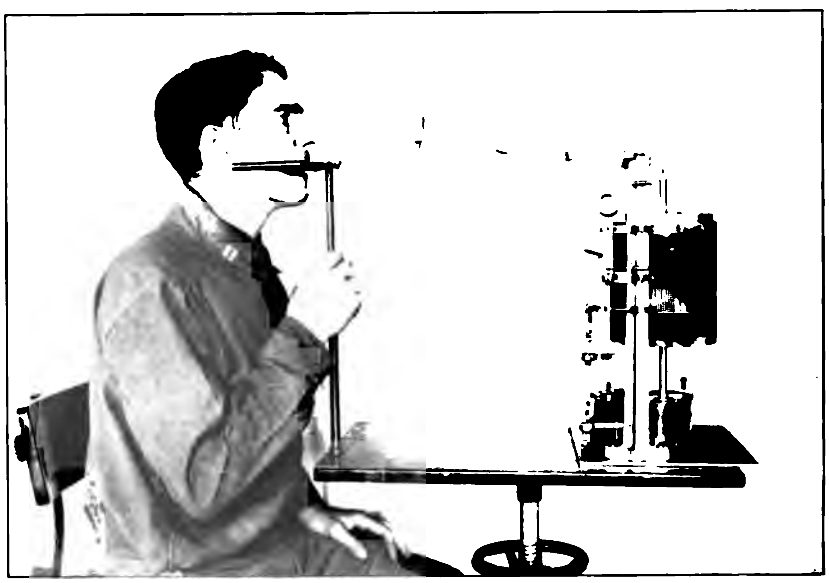


OPHTHALMOLOGICAL EXAMINATION OF THE FLIER DURING LOW-OXYGEN TENSION EXPERIMENT.

PRELIMINARY.

Visual acuity.—A Snellen test card is hung on a level with the candidate's eyes, at a distance of 20 feet. Uniform illumination is obtained by the use of a 75-watt nitrogen daylight lamp, placed 1 foot from the card, at an angle of 45 degrees.

The left eye is covered and the vision of the right eye recorded in feet. (Ex. 20/20, or if three letters are missed in the 20/20 line, 20/20–3.) The right eye being covered, the vision of the left eye is determined and recorded in the same manner. Place a trial frame before the eyes and cover the left eye, place a high plus sphere before the right eye and add minus spheres until the best line read without the use of a lense is again distinct. This procedure is repeated for the left eye, and the strongest convex lens which still permits clear vision is recorded.

RETINAL SENSITIVITY.

A. *Contrast sensitivity.*—(1) This is the test to be used in the routine preliminary examination. The test object is made by pasting a 1-inch square of gray paper on a 2-inch square of lighter gray paper where there are 13 perceptible differences between the two squares. The two squares are mounted on a 5-inch square of heavy cardboard for handling. The test object is placed slightly above the level of the subject's eyes at a distance of 20 feet. A 75-watt, 110-volt daylight lamp at a distance of 8½ inches and at an angle of 45 degrees is used to illuminate the test object. The Reeve's wedge is made by coating a neutrally dyed gelatine in a wedge shape on plate glass so that the absorption of light varies with the thickness of gelatine deposit. A cover glass is cemented over the gelatine for protection. The subject is told the principle of the wedge and what to look for when viewing the test object through the wedge. Before making any readings the subject should be shown how to keep his pupil in line with the aperture in the wedge case. The subject, with both eyes open, then draws the wedge from its case until the contrast just disappears and the larger square appears uniform. When the pupil is in line the examiner should give the word for the wedge to be drawn out of the holder. The rate of movement should be so regulated that the contrast disappears in not less than five nor more than eight seconds. Repeat until three readings have been obtained and if these results are not too discordant their average represents the threshold for the subject.

(2) A 20/50 Snellen illiterate "E" is used instead of the smaller square and the subject should be able to tell which direction the "E"

points when it is shifted—as he observes it through the wedge. This test is to be used in special cases; suspected malingering, etc.

B. *Threshold sensitivity.*—This procedure may be employed to check the contrast sensitivity test.

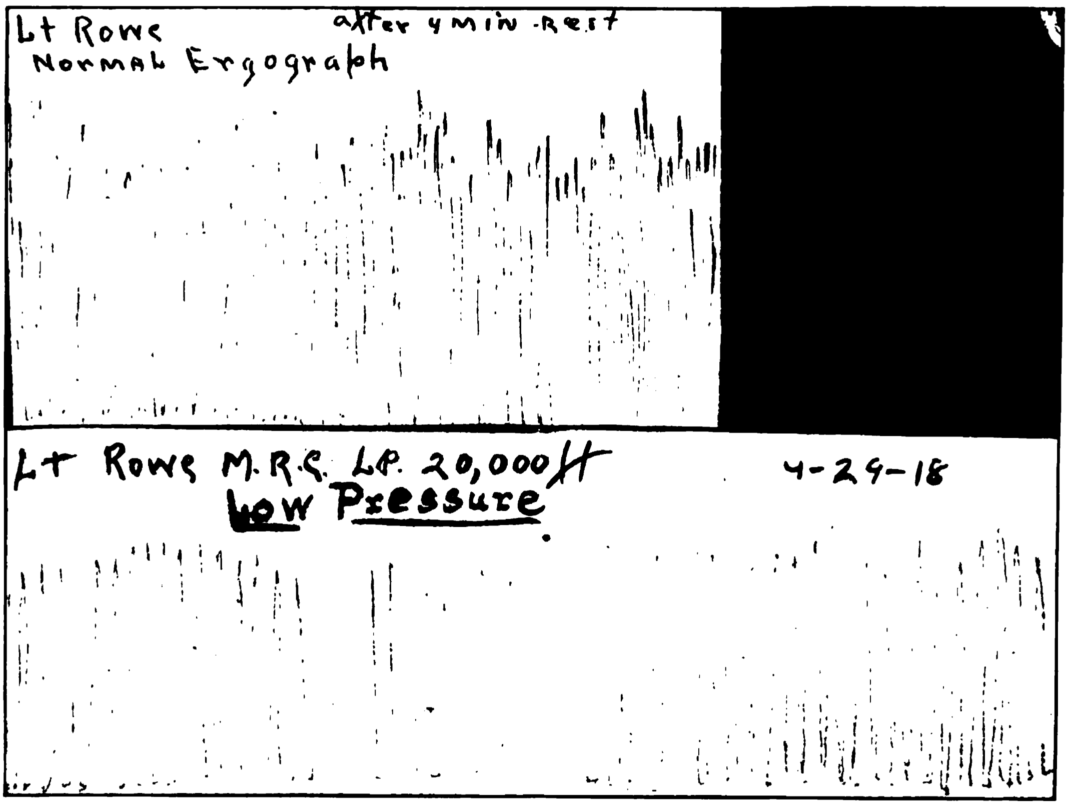
At the regular distance of 20 feet, with the Reeves wedge before the right eye, the observer looks at a 3-millimeter aperture in the iris diaphragm on the De Zeng stand. A 36-watt 110-volt Mazda lamp with a frosted globe is used as the source of illumination, the candidate looking through the aperture in the wedge with the right eye. The wedge is drawn out until the light just becomes invisible, the rate of movement to be the same as in the determination of contrast sensitivity. The reading of the scale on the wedge represents the threshold for the adaptation to the brightness of the room. (The absolute threshold would be represented by a similar procedure when the eyes were completely adapted to a total darkness.) At least three readings should be taken for this threshold and, if the results are too discordant, the examiner should repeat directions and closely supervise the procedure. When giving directions, the examiner is getting the aperture in the wedge apparatus centrally aligned with the pupil. This threshold value represents the least that can be seen for the particular adaptation of the retina. (The examiner should always bear in mind that the threshold value differs greatly for different brightness adaptations and different states of adaptation to the same brightness.) The average reading for the wedge should be determined for special conditions found at each laboratory. If the eye is to be adapted in an absolutely dark room, for practical purposes, the adaptation would be complete in 20 minutes. If the candidate is to be adapted for a light room of known brightness, for instance, a 75-watt nitrogen daylight lamp in a dark room, 15 by 10 by 8 feet, 5 minutes' adaptation would be sufficient.

MUSCLE BALANCE—THE ROUTINE.

The subject's eyes should be on a level with and directly facing a 1-centimeter black dot on a white card or the 1 centimeter opening in the iris diaphragm on the De Zeng stand, 20 or 25 feet distant. It is most important to see that the candidate's head is held in the vertical plane if errors in determining the amount of hyperphoria are to be avoided. If a phorometer or Maddox rod is used, it is well to check the findings with the screen and parallax test.

MADDOX ROD TEST.

A trial frame with a red multiple Maddox rod, properly centered before the right eye, should be carefully adjusted so that there is no sagging from the horizontal plane. The eyes are fixed on the light source and the left eye is covered to make sure that the single bar


Lt Rowe
after 4 min. Rest
Normal Ergograph
Lt Rowe M.R.C. L.P. 20,000 ft
4-29-18
Low Pressure

of light is accurately observed, running horizontally, when the rod is vertical, and vertically when the rods are horizontal. The left eye is uncovered and the candidate states the exact position of the red line in relation to the light. If the red line, when vertical and horizontal, runs directly through the light orthophoria obtains for distance. If the vertical red line is to the left of the lights (crossed diplopia) there is exophoria. If the line is to the right of the lights (homonymous diplopia) there is esophoria. The prism, placed base in before the left eye in exophoria and base out in esophoria, which causes the line to run through the lights is the measure of the horizontal imbalance. If the horizontal line is above the light there is left hyperphoria; if below the light, right hyperphoria; and the prism, base up or down, which causes the line to run through the light, is the measure of the vertical imbalance. To remember that high eye means low image; and, when the eyes are uncrossed, the diplopia is crossed, may help one in the study of the heterophorias.

Some candidates may not understand the rod test, or they may have been coached to say that the rod runs through the light, so always check the findings with the screen and parallax test or use the rod in combination with a prism which would produce a known deviation of the line.

SCREEN AND PARALLAX TEST.

The candidate is seated 6 meters from a 1-centimeter light on a black field or a 1-centimeter black dot on a white field, which he fixes intently. Shift a card quickly from eye to eye and note any movement of the eye as it is uncovered and ask the candidate to describe any movement of the eye or the light. Orthophoria obtains if there is no apparent movement of the eye or the light. Movement of the test object or eye with the card signifies exophoria; against the card, esophoria; and vertical movement, hyperphoria. Prisms are placed with the base in for exophoria, out in esophoria, up before the right eye in left hyperphoria, and down in right hyperphoria, until the test object and the eye just begin to move in the opposite direction. The weakest prism which causes reversal of movement, minus 2 prism degrees, is the measure of the heterophoria. If there is less than 5 degrees of heterophoria, only 1 prism degree is subtracted.

N. B.—In hyperphoria first correct the horizontal imbalance and then superimpose the square prisms to determine the amount of vertical imbalance. The prism which just stops the movement gives the measure of the hyperphoria.

If muscle imbalance of more than 1 degree is found in either plane, the Maddox rod and screen and parallax tests should be made at 14 inches, using a 2-millimeter black dot on a white card or the light of

the Hare-Marple ophthalmoscope as the test object. The converging, diverging, and sursumverging power should also be taken and recorded on back of the 5 by 8 history card.

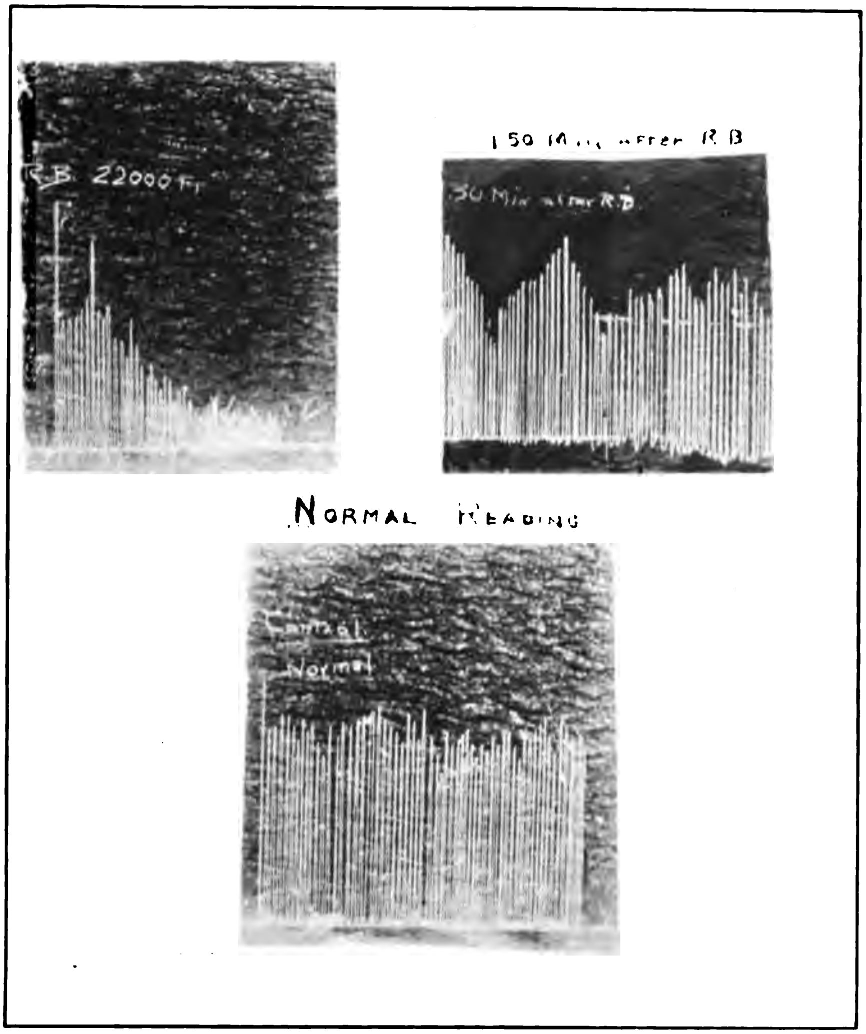
Example.—In testing the power of convergence the subject fixes the 1-centimeter black dot at 20 feet, and prisms of increasing strength are placed, base out, before either eye until the diplopia produced can not be overcome. The strongest prism through which binocular single vision is obtained is the measure of the converging power. Practice is important, especially in determining the power of convergence. It is well to begin with a very weak prism and gradually increase the strength, permitting the subject to close his eyes and then open them quickly when he has difficulty in fusing the test object. In testing the diverging power, prisms are placed base in and gradually increased in strength. To make certain that the candidate is really fusing, the prism may be rotated a little, producing a vertical diplopia, and then brought back to the horizontal, or the eyes may be screened alternately and any movement of the unscreened eye noted. The right sursumverging power is tested with the prism base down. Before making a definite statement as to the strength of the muscles it is well to have the candidate return several times, for, as has been said, practice and knack play a great part in this examination. Always test the divergence first, then the sursumvergence, and finally the convergence.

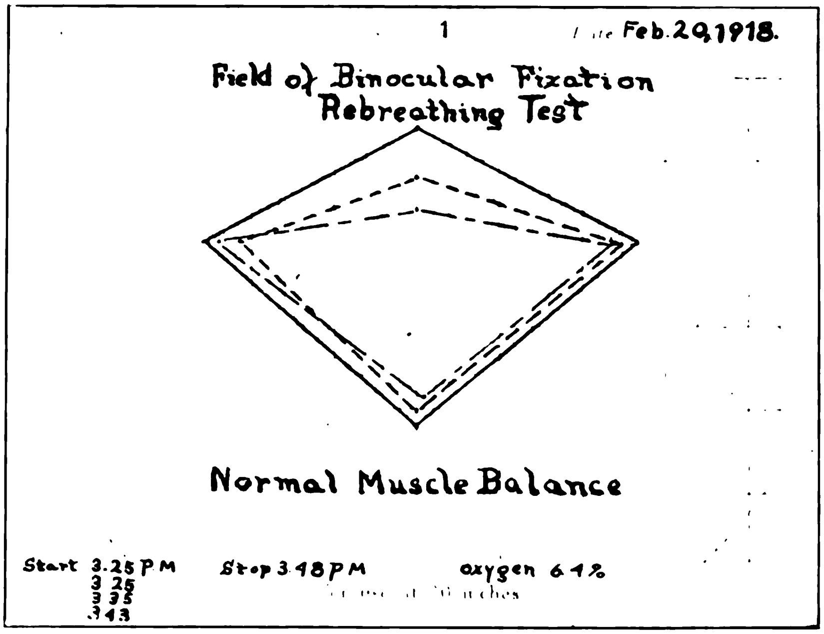
MUSCLES.

If there is a marked imbalance of the ocular muscles, it will be well to use a black wall as a tangent screen and make a record of the diplopia in the various fields as obtained by the use of the ruby glass and light at a distance of 30 inches from the wall. This should be recorded on the tangent screen charts which have been provided and filed with the 5 by 8 history card.

ACCOMMODATION (NEAR POINT).

The near point accommodation is measured by means of the Prince rule, using the type Jaeger No. 1, or the Duane disk, as the test object. The Prince rule has been gouged out at one end to permit its use in the midline, as in this way it can be placed over the nose, in contact with an ink mark which is 12 millimeters in front of the cornea. This point is measured by placing a millimeter rule alongside the forehead and, with the gaze fixed straight ahead, 12 millimeters are measured off. The point thus determined is marked on the nose. The test object is brought slowly toward the eye until the first sign of blurring is noted. This procedure is repeated several times, instructing the candidate to exert all his power so that the test object


R.B. 22000 Ft
NORMAL READING
Control
Normal


1
Feb. 29, 1918.
Field of Binocular Fixation
Rebreathing Test
Normal Muscle Balance
Start 3.25 P M
3 25
3 35
3 43
Stop 3.48 P M
oxygen 6.4%

may be brought as close to the eye as possible, for we know that the first contraction of a muscle is seldom its strongest. The reading at which the test object was brought closest to the eye is recorded in millimeters. It is well to have a good light from a 75-watt nitrogen daylight lamp shining directly on the type, and the test is more accurate if the test type is held slightly below the horizontal plane.

PUPILLARY DIAMETER.

With the candidate seated in the chair in which he is to be tested, and with the same light that will be used later on, he is asked to fix a distant object. A millimeter rule is inverted above the pupil with a plus 2.75 sph. superimposed, and the reading is made while looking through the lens. If greater accuracy is desired, a pupillometer should be used.

COLOR VISION.

For this purpose Jenning's color test is used. The method of making the test: The cover of the green side of the box is removed, the color board is lifted out, a record sheet inserted, and the color board replaced. In replacing the color board CARE MUST BE TAKEN TO SEE THAT ITS TOP, MARKED ON THE BACK "NO. 1 GREEN," CORRESPONDS TO THE TOP OF THE RECORD SHEET. The box is now turned around several times until all sense of direction is lost. The green test skein, fastened to the inside of the box lid, is placed at a distance of 2 feet and the candidate is given the stylus and requested to look along each row of colored patches and when he sees the test color, or one of its lighter or darker shades, he is to place the point of the stylus in the opening and punch a hole in the paper beneath. Have him understand that he is not expected to find an exact match for the test skein but that he is to indicate all the color patches that appear to him to be same general color as the test skein, both those that are lighter and those that are darker in shade. Having completed Test No. 1, the record sheet is removed, the cover is replaced, and the box turned over, exposing Test No. 2, the ROSE. The same record sheet is placed under the rose color board, CARE BEING TAKEN TO HAVE THE TOP OF THE RECORD SHEET AND THE TOP OF THE COLOR BOARD, MARKED ON THE BACK "NO. 2 ROSE," correspond. The rose test skein is now displayed and the test proceeds as before. If the candidate seems to have been uncertain in the selection of colors or you suspect that he may have been coached in the test, turn the card with the colored wools and the blank on the reverse side and have another reading made. An-

other way to confuse the subject is to cut a circle in a piece of paper and place it over the peripheral skeins.

REACTION OF THE IRIS TO LIGHT AND ACCOMMODATION.

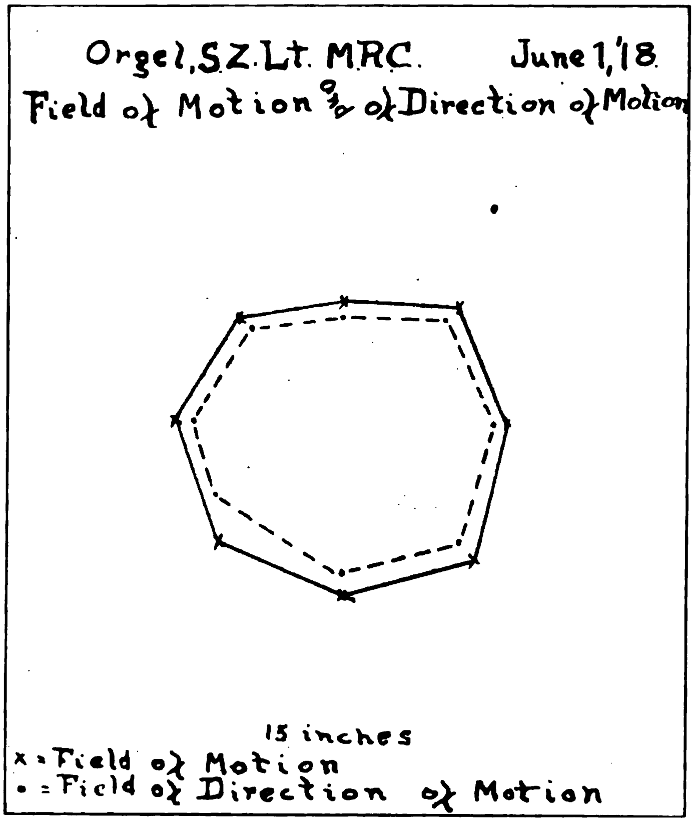
The reaction of the iris to direct and indirect light and accommodation is noted and recorded as plus (meaning reacts) 1, 2, and 3, being increased reaction, minus 1, 2, and 3 meaning degrees of sluggish reaction, and 0 no reaction. The reaction to accommodation is determined by requiring the candidate to look in the distance and then fix on a 2-millimeter black dot on a white card held 10 centimeters in front of the eye. The reaction to light is best taken in a dark room, requiring the candidate to look into the distance and directing light from the Hare-Marple ophthalmoscopic mirror through the pupil and noting the reaction in both eyes. It may be taken more roughly, with the candidate facing a window and fixing a distant object, both eyes being covered; the covers are removed alternately and the reaction to direct and indirect light noted.

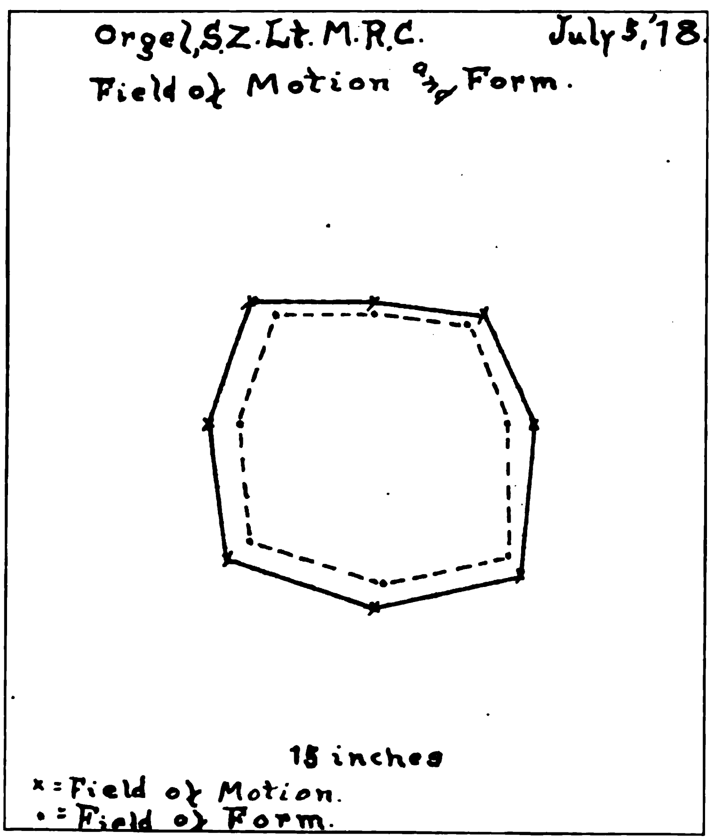
NEAR POINT OF CONVERGENCE.

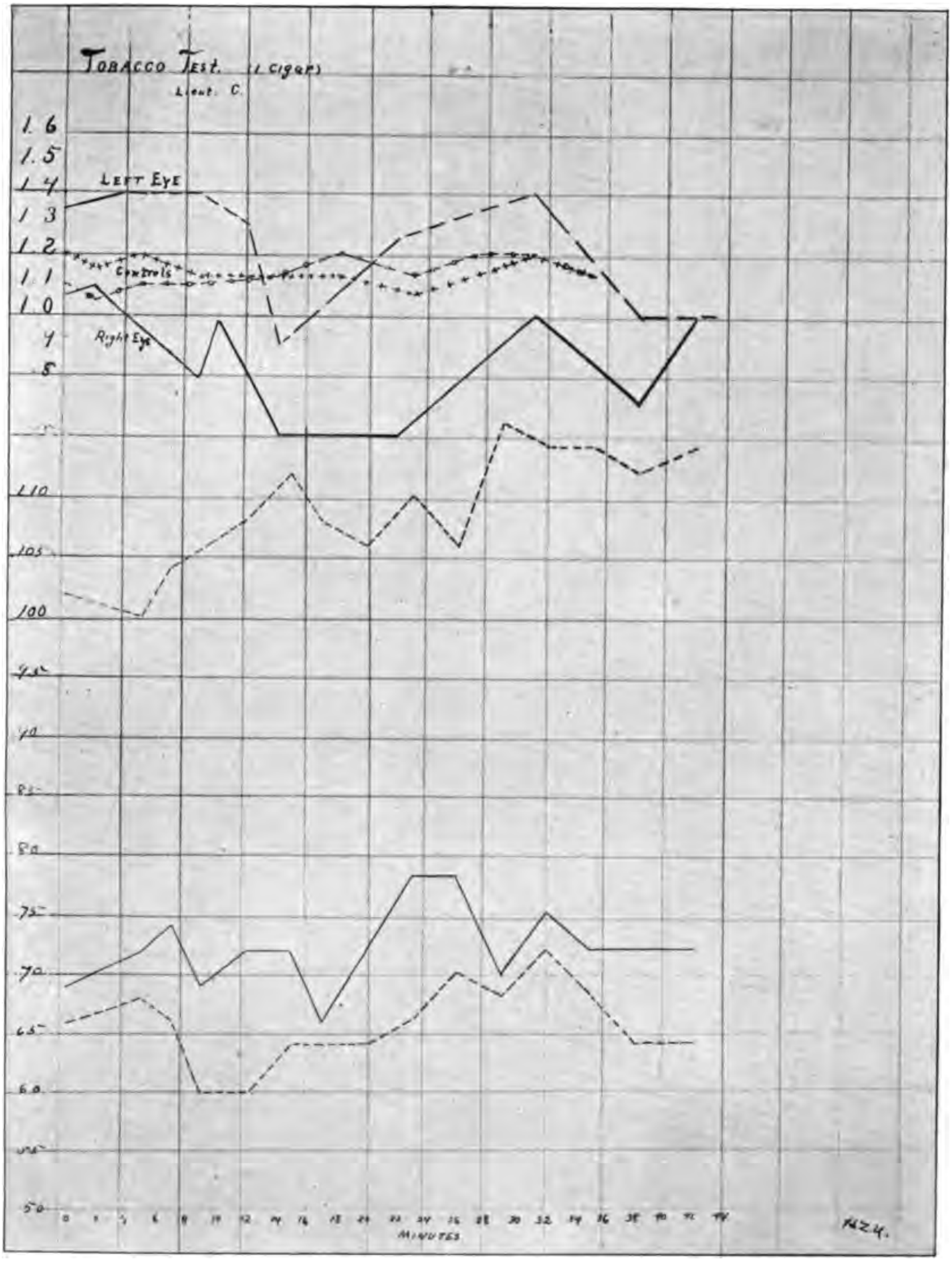
The Prince rule and a 2-millimeter black dot as a test object are used. The end of the rule rests across the bridge of the nose at a point 12 millimeters in front of the cornea. The test object is brought slowly toward the eyes slightly below the horizontal plane until there is a doubling of the dot or one or both of the candidate's eyes ceases to fix. The test is repeated several times, instructing the candidate to exert his maximum effort, and the reading which was closest to the eye is recorded.

STEREOSCOPIC VISION.

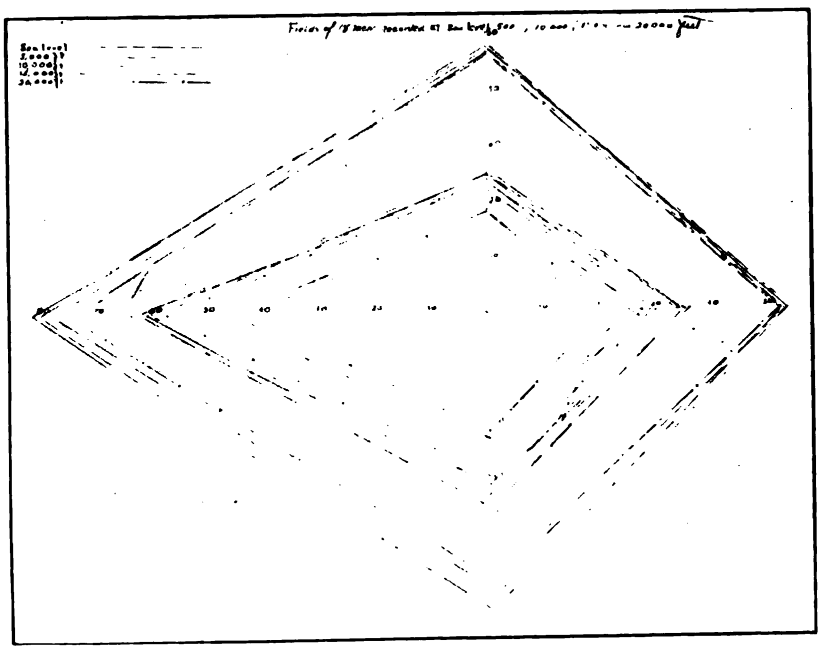
An ordinary stereoscope and the A, B, and C cards are furnished. The stereoscope should be held away from the candidate's eyes and gradually brought up to them, instructing him that he is to look at the pictures just as he would look at objects in a show case in a store window. He is then asked to move the card backward and forward until the point is reached at which the pictures are most distinct, and his eyes are most comfortable. He is then asked to name the objects by number as he sees them, from before backward. The usual order with the A card is 9–1–7, 3–2–4, 5–6–8, and 10. Confusion of 4 and 5, 9 and 1, and 8 and 10 is permissible. To further test the candidate on the same card, he may be asked to name the smaller objects on No. 9, from before backwards, they are cross, balloon, and flag. On No. 8, balloon, cross, rod, and pennant. No. 10, pennant, balloon, and cross. The usual order for the B card is 7–5–9, 3–4–2, 1–10–8, and 6; for the C card, 10–9–2, 7–8–6, 4–3–1, and 5.

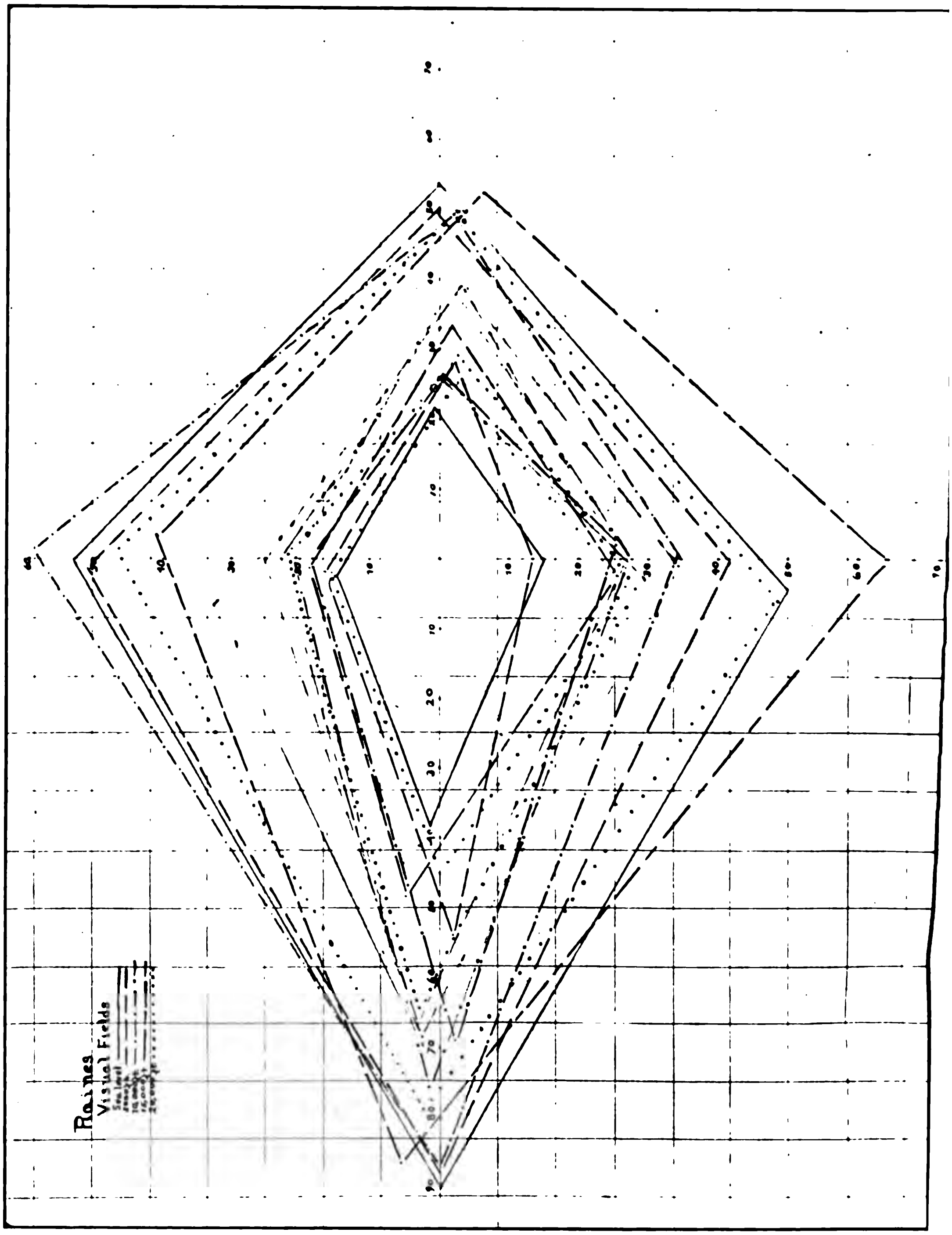

Orgel, S.Z. Lt. M.R.C. June 1, '18
Field of Motion and of Direction of Motion
15 inches
x = Field of Motion
• = Field of Direction of Motion


Orgel, S.Z. Lt. M.R.C. July 5, '18
Field of Motion and Form.
15 inches
x = Field of Motion.
• = Field of Form.



Tobacco Test. (1 cigar)
Lieut. C.
Left Eye
Controls
Right Eye
Minutes
Fig. 4.


Sea level


Raines
Visual Fields

OPHTHALMOSCOPIC EXAMINATION.

The direct and indirect methods should be used, noting any changes in the lens, media, or fundus.

PRELIMINARY REPORT OF THE RESEARCH WORK OF THE OPHTHALMOLOGICAL DEPARTMENT, MEDICAL RESEARCH LABORATORY, JULY 17, 1918.

Although the number of men examined has been few and the research work carried out under adverse conditions, an outline of the results so far accomplished may prove of some value in helping us care for the flier in a more scientific manner.

The most important problem is the one of visual acuity, and it is absolutely essential that the pilot or observer have as nearly perfect vision as nature permits under normal conditions, and furthermore that the visual acuity will not show a marked deterioration due to the lack of oxygen.

Visual acuity has been studied using Ives' test object and Johnson's visual acuity test apparatus and also with the ordinary Snellen test type. The Ives' visual acuity test object has been found to be of the greatest value for taking the visual acuity on the rebreathing apparatus, due to the fact that the subject could raise his hand when he first perceived the lines. In the low-pressure chamber it has also proven of value, for the first surface mirror could be used to increase the reading distance.

Forty-four subjects were examined on the rebreathing apparatus and in the low-pressure chamber. They were classified as normal and subnormal; i. e., those who could pass the examination for the Department of Military Aeronautics and those who would be ocularly disqualified. The 13 subnormal subjects were so classified because of defective vision arising from errors of refraction.

	Normal.	Subnormal.
Vision improved	3 (10 per cent)	
Vision decreased	8 (26 per cent)	5 (38.5 per cent).
No change	20 (64 per cent)	8 (61.5 per cent).

One of the French observers claimed that the visual acuity increases at an altitude of 2,000 meters and that this was probably due to congestion of the head and in particular of the choroid and retina. Normal visual acuity readings were taken, using the Johnson apparatus, then a three-minim pearl of amyl nitrite was inhaled to produce congestion. Twelve men were examined and there was impairment of vision during the period of maximum nitrite effect in all except one, a myope. During the first stage of the action of the drug there was a slight increase in visual acuity in most instances.

The effect of tobacco upon the visual acuity has also been studied. Smoking one strong cigar or inhaling one or two cigarettes, controls were made in most instances. Twelve or 75 per cent showed falling off in visual acuity over the control, 6 per cent showed a rise, and three, or 19 per cent, showed no change. This subject will be taken up in full under the effects of tobacco on the eye.

REACTION TIME.

The French and Italians have laid great stress upon the determination of the reaction time, and it is undoubtedly important that the pilot or observer act and think a little more rapidly than his adversary, if he is to have the advantage. All the men who have done the most work in reaction time in this country believe that some form of complex reaction time will prove of value, but they are skeptical as to the results obtained with the simple reaction time tests employed by the French and Italians. With this in mind the ——— visual discrimination reaction time experiment with four possible correct reactions and five possible stimuli has been chosen. The subject presses the telegraphic key the moment the stimulus appears upon the ground-glass plate. The ——— chronoscope starts recording time the moment the light appears on the ground glass and is stopped by the subject's reaction. The chronoscope records time in 0.12 of a second and the average discrimination reaction of a normal subject is approximately one-half second, and for simple reaction time one-fifth of a second.

JUDGMENT OF DISTANCE AND STEREOSCOPIC VISION.

There are many factors involved in the judgment of distance, but undoubtedly stereopsis is of importance in the accurate performance of this complex act and therefore it has been considered important that the stereoscopic vision be tested under conditions of low-oxygen tension.

The stereoscopic vision was tested on the rebreather and in the low-pressure chamber by use of the ordinary stereoscope containing 7-degree prisms, base out, with a plus 5.50 sphere superimposed. The ability to maintain perfect stereopsis at high altitudes was noted.

Nineteen normal subjects were examined on the rebreather with a loss of stereopsis in only three of them, or 15.7 per cent. Readings were taken at six-minute intervals throughout the run. Of seven men ocularly disqualified stereopsis was lost in only one. In no case was a change noted below 20,000 feet.

Seven "normals" and nine "subnormals" were examined in the low-pressure chamber. Here readings were taken at 10,000, 15,000,

and 20,000 feet. All seven normals remained unchanged and only one subnormal showed any confusion in stereopsis. This change was noted at 15,000 feet, but normal stereopsis was promptly restored by the administration of oxygen.

COLOR VISION.

Color vision is considered important for the flier by most of the allied nations, and certainly it plays an important rôle in judging the color of fields and swamps in landing. To accurately determine the color of roofs, chimneys, lights, etc., particularly colored lights at night, good color vision is surely necessary. We have endeavored to determine the effect of low-oxygen tension upon color vision. Stillings plates were used in these tests. Five subjects were carried to 20,000 feet or over in the low-pressure chamber and five above 20,000 feet on the rebreathing apparatus. There was no change in color vision during these tests.

FIELD OF BINOCULAR SINGLE VISION AND FIELD OF BINOCULAR FIXATION.

The field of binocular single vision has been tested by means of a tangent screen. The field of binocular fixation has been tested by the use of the modified Schweiger perimeter and small dots on a white card. One hundred and twenty-two men with normal eyes were examined and 16 who were ocularly subnormal. Seven and thirty-seven one-hundredths per cent of the normals showed contraction of the field of binocular fixation. Fifty per cent of the subnormals showed this contraction. Contraction of the field was more marked above.

MUSCLE BALANCE AND MUSCLE STRENGTH.

It is important for the flier that his muscle balance be as nearly normal as possible, for small defects are accentuated by the strain of flying and lack of oxygen, resulting in a marked contraction of the field of binocular single vision, and sometimes diplopia is produced, even at low altitudes. Research work has demonstrated that exophoria and hyperphoria are more objectionable than esophoria.

To determine the effect of lack of oxygen upon the ocular muscles 35 men, acceptable for the Air Service, have been examined on the rebreathing apparatus and the findings checked by repeating the test in the low-pressure chamber. The muscle duction was taken at sea level, 5,000, 10,000, 15,000, and 20,000 feet, and at this point oxygen was given in the low-pressure chamber for five minutes, and on the rebreathing apparatus the mouthpiece was taken out, allowing the subject to breathe normally. Oxygen or breathing

atmospheric air caused a return of the muscle strength to normal in from three to five minutes. The general averages of the strength of the muscles at sea level is as follows:

	Superduction. 2.8°	Abduction. 6.2°	Adduction. 16.8°
Loss of strength during the rebreathing test:	° P. ct.	° P. ct.	° P. ct.
15,000 feet or 11.8 per cent oxygen	1.1 (39)	1.5 (24)	1.8 (9.5)
20,000 feet or 9.7 per cent oxygen	1.9 (70)	1.83 (29)	2.94 (17)
Loss of strength during low pressure chamber test:			
15,000 feet or 11.8 per cent oxygen	1.05 (37)	1.35 (21)	1.75 (10)
20,000 feet or 9.7 per cent oxygen	1.7 (64)	1.8 (29)	2.8 (16)

In all the subnormal subjects examined, particularly those with convergence insufficiency alone or combined with divergence excess, there was a marked loss in the power of adduction, and diplopia often occurred between 10,000 and 15,000 feet. Men with over one degree of hyperphoria, particularly when combined with exophoria, showed a rapid reduction in muscle strength, often resulting in diplopia. Subjects in the subnormal group should be cared for by muscle exercises and operations where it is found necessary.

FIELD OF VISION.

It is of the utmost importance that the aviator have the broadest possible field of vision, for we know that the visual field is contracted slightly, due to the lack of oxygen, and that marked constriction of the field is produced by poorly constructed goggles as well as by blind angles in aeroplane construction. The fields for form and color have been taken in the low-pressure chamber at 5,000, 10,000, 15,000, and 20,000 feet, and when contraction is noted at 20,000 feet oxygen is administered. To make sure that the changes are not due to fatigue, controls have been taken at sea level, corresponding in time of day and in time interval to those taken in the low-pressure chamber. At 5,000 and 10,000 feet there is usually a slight enlargement of the fields for form and color, at 15,000 feet a slight contraction, and at 20,000 feet a marked contraction. Twenty men have been examined, and at 20,000 feet the fields for form have shown a contraction of 14 per cent of their original size below, 3.5 per cent in the temporal field, 4 per cent above, and 6 per cent nasally. The green, 4.5 per cent in the lower, 5 per cent in the temporal, 5 per cent above, and 25 per cent in the nasal field. Five minutes after returning to sea level fields are normal in size. Giving oxygen at 20,000 feet for four or five minutes caused a return of the fields to normal. Several fields have been taken on the rebreathing apparatus, and the results are fairly comparable with those found in the low-pressure chamber.

PERCEPTION OF MOTION BY THE RETINA.

It is important that the aviator note the approach of an enemy plane before the enemy sees him, and therefore the keen sense of perception of motion by the retina is a valuable asset to the flier. It has been our endeavor to provide some method of taking and recording these fields in the hope that something of practical value might be found.

These fields were taken in a dark room with no illumination other than that of the test object, for which purposes a May ophthalmoscope battery handle with the cap removed was used.

The subject was seated at a distance of 15 inches from the center of the screen. The test object was held on the opposite side of the screen from the object and gradually moved until it came into the field of vision. In this manner the place at which the motion of the light could be first seen was noted, and then at what point the correct perception of direction of motion could be ascertained. Lastly, the field of form was taken, i. e., the first point at which the stationary light could be recognized.

The relative sizes of these three fields can be seen by the average figures of 10 cases:

	Field of motion.	Field of direction of motion.	Field of form.
Up	33	31½	29¾
Down	47½	45	42½
Right	45	42	40
Left	47	43	42¾
Up and right	42	40	35
Up and left	41	38	36
Down and right	48	45	43
Down and left	47	44	43

The field of motion is approximately 3 degrees larger than the field of direction of motion, which, in turn, is about 1½ degrees larger than that of form. It is evident, then, that a moving object can be seen 4½ degrees sooner than a stationary one. That is, the field of motion is 4½ degrees larger in every direction than that of form. This relationship is apparently a constant one, independent of the size of the field. In other words, if motion is perceived at a certain point, you expect to find the perception of form 4½ degrees farther in toward the center. In a like manner the field of perception of direction of motion bears a rather constant relationship to that of motion and of form.

INTRAOCULAR TENSION.

Intraocular tension has been studied in the low-pressure chamber. Fourteen men have been examined in the low-pressure chamber. No correlation has been found, either between intraocular tension

and the blood pressure or lowered oxygen tension and various cardio-vascular changes, for the intraocular tension has sometimes gone up as the barometric pressure was lowered and sometimes it has gone down with the lowering of barometric pressure. This also holds true for the blood pressure. However, before definite conclusions should be made more work should be done.

ACCOMMODATION.

The flier must continually observe the instruments on the inside of the fuselage, particularly at night, and therefore it is important that the accommodation should not fall off too rapidly, due to lack of oxygen. The rule of accommodation in visual acuity and in judgment of distance is also important.

The near point of accommodation has been taken every two minutes in the low-pressure chamber and on the rebreathing apparatus, using a Prince rule with Jaeger test type or the Duane disk as a test object. Normal runs have been made without the low oxygen tension effect for the purpose of comparison. One hundred and forty-eight men, acceptable for the Aviation Service as fliers, were examined on the rebreathing apparatus; 44.6 per cent showed a receding of the near point, 18 per cent showed improvement, fluctuating changes in accommodation were noticed in 14.4 per cent, and no change in 23 per cent. Eleven subnormal cases were examined, and 63.7 per cent manifested a decrease in accommodative power, 18.3 per cent an apparent increase, 9 per cent showed no change, and 9 per cent variable reactions. The low pressure chamber findings were practically the same as those with the rebreather. Of 17 normal men examined, 47 per cent showed decrease in accommodative power, 11.7 per cent increase, 23 per cent fluctuation, and 7.8 per cent no change. Three subnormal subjects were examined in the low-pressure chamber; two showed a decrease in accommodative power and the other gave a varying reaction. When the subject is brought to sea level the accommodation comes back rapidly in some and slowly in others. The inhalation of oxygen invariably causes a return to normal, even though the subject may be kept at 20,000 feet in the low-pressure chamber.

That these changes do not follow the cardio-vascular reactions is shown by the fact that 57 men, exhibiting acceleration of pulse rate and maintenance of pulse pressure, showed in 42.1 per cent decrease in the power of accommodation, 15.8 per cent increase in power of accommodation, 15.8 per cent fluctuation in accommodation, and 26.3 per cent no change in accommodation. Our researches would lead us to believe that hyperopes and subjects with a marked amount of hyperopic astigmatism show the most marked changes in accommodation.

Fatigue of accommodation has been studied with an ophthalmic ergograph. Normal three-minute runs were made without the low oxygen tension effect as controls, then three-minute runs with same time interval were made in the low-pressure chamber and on the rebreathing apparatus. The findings on the rebreathing apparatus and in the low-pressure chamber showed, at 15,000 feet, a more rapid onset of fatigue than was evidenced by the controls, and at 20,000 feet the fatigue was marked. The administration of artificial oxygen rapidly restored the normal tone of the ciliary muscle.

CONVERGENCE.

If the near point of convergence falls off markedly during flying, the aviator's ability to make landings properly will be impaired, and, therefore, the near point of convergence has been taken during the rebreathing test and low-pressure chamber experiment.

A U-shaped piece was cut out of the Prince rule to fit over the nose and a 2-millimeter black dot on a white background was used as a test object for making this determination. Readings were taken without low-oxygen tension effect, with low-oxygen tension effect, and the effect of the administration of oxygen was determined. Readings were taken every two minutes and charted. One hundred and forty-seven men with normal eyes were examined on the rebreathing apparatus.

50.3 per cent decrease in convergence power.
17.6 per cent increase in convergence power.
11.5 per cent fluctuation in convergence power.
20.6 per cent no change in convergence power.

Of 11 subnormal men examined 6 were disqualified for visual acuity and 5 for muscular imbalance; 45.7 per cent showed decrease in power of convergence. Increased converging power, fluctuating changes, and no change in the near point of convergence were each noted in 18.1 per cent. Of 16 normal men examined in the low-pressure chamber 50 per cent showed falling off in power of convergence, none showed increase, fluctuating reactions were present in 12.5 per cent, and 37.5 per cent remained unchanged. In the subnormal group the recession of the near point of convergence was very marked, sometimes resulting in diplopia.

An attempt has been made to show what relationship, if any, exists between the convergence and the cardio-vascular reactions to low-oxygen tension.

Seventy-two cases showing an increase in pulse rate and a maintenance in pulse pressure gave these convergence changes, which

would seem to indicate that ocular changes can not be predicted by the cardio-vascular reaction and vice versa.

54.2 per cent decrease in power of convergence.
15.3 per cent increase in power of convergence.
9.7 per cent fluctuation in power of convergence.
20.8 per cent no change in power of convergence.

The results would indicate that the rebreathing apparatus and low-pressure tank give almost identical findings, and in each case the determining factor seems to be the lowering of oxygen tension as the administration of oxygen soon causes the convergence near point to return to normal, irrespective of the barometric pressure.

Fatigue of convergence has been studied with Howe's ophthalmic ergograph. Normal 3-minute runs as controls were made without the low oxygen tension effect, then 3-minute runs with approximately the same time interval were made in the low-pressure chamber and on the rebreathing apparatus. The findings on the rebreathing apparatus and in the low-pressure chamber showed a more rapid onset of fatigue than occurred with the controls. At 15,000 feet and at 20,000 feet the fatigue was marked, as was the case with accommodation. Here also the administration of oxygen caused a rapid return of converging power.

RETINAL SENSITIVITY.

The Italians have laid considerable stress upon retinal sensitivity for those men who must fly at night, and Lieut. ——— has devised a test for the contrast sensitivity of the retina which has proven most useful and practical.

It is important that the retina be normally sensitive to light impressions, especially for those men who must fly at night, notably bombers and fliers doing patrol duty. A test for the contrast sensitivity of the retina has proven most practical for our work, and only men who have normal sensitivity in this respect will be selected for night flying.

In this laboratory tests to determine the threshold sensitivity for white and colored lights and for contrast are conducted in the following manner:

The ——— wedge is made of two pieces of glass at a known angle, between which is run a solution of gelatine and neutral dye. The wedge is calibrated in millimeters, which is translatable into per cent of light transmitted.

To test the threshold sensitivity to light the subject is placed 20 feet from a spot of light 3 millimeters in diameter. Holding the wedge before the right eye, he slowly draws the slide from its cover,

and as the light just disappears a reading is taken. This reading is in millimeters and is then translated to per cent transmission.

The threshold for color is taken the same as the above, using red and green light, which are practically monochromatic.

The test of contrast sensitivity is made with a ——— wedge and ——— contrast square. The contrast square is made by placing a square of dark gray paper upon a larger square of lighter gray, there being 13 perceptible differences between the two shades. An illiterate "E" with the same perceptible differences is used as a check of the findings. This is lighted by a 75-watt nitrogen daylight lamp at a given angle and distance from the test object and the subject is placed 20 feet in front of the object. The reading on the wedge is taken just as the contrast between the squares disappears. The average readings taken with the contrast sensitivity square give 34 millimeters and the illiterate "E" 32 millimeters. To date, the normal for the light threshold of 35 cases is 65 millimeters.

Under the rebreathing test the threshold for light has shown an improvement in 25.9 per cent; 44.5 per cent show neither improvement nor falling off; and 29.6 per cent show a falling off in sensitivity.

In the study of the threshold for colors the red and green both show a falling off in 71.4 per cent and neither a gain or loss in 26.6 per cent.

In former tests with a blue light, which was not absolutely monochromatic, there was improvement in 66.6 per cent and falling off in 33.4 per cent.

ACCOMMODATION TEST OBJECT.

It has been important for our work to determine the best possible test object for determining the near point of accommodation.

The object of these tests is to determine the comparative value of various test objects used in determining the near point of accommodation. Tests were also made to determine the difference, if any, between a black and white dot in determining the near point of convergence. The objects used in these tests were as follows:

1. Radiating squares.
2. Illiterate "E."
3. Numbers.
4. Jaeger type, No. 1.
5. Duane disk.
6 Prince rule.

Two separate examinations were made for each test object. Twenty-five men were examined, and a general average gave the following results of difference in readings

	Millimeter.
Radiating squares	14⅓
Illiterate "E"	4½
Numbers	5½
Jaeger, No. 1	4½
Duane disk	3¾

The Duane disk is the best test object for general use. It is found, however, that during the rebreathing test it is difficult for the subject to quickly recognize the faint black line on the disk, and the later readings are not satisfactory. Tests of black and white dots in finding the near point of convergence show no appreciable difference between them.

As Jaeger type is not standardized, and as the various units should have some standard in order to obtain uniform results, a plate has been made with two sizes of standard type. This type is made up of mixed letters and numbers. The smaller type is 0.6 millimeter and the larger 0.8 milimeter, so, should the accommodation fall off late in the tests, the larger type can be seen. Above the letters is a black dot for use in determining the near point in convergence, thus eliminating a certain amount of delay in changing cards during the test.

ASTIGMATISM.

The effect of lowered barometric pressure and lack of oxygen upon astigmatism has been tested in several instances, and so far no change has been shown in astigmatism due to lack of oxygen or lowered barometric pressure.

EXAMINATION OF THE FUNDUS DURING REBREATHING AND LOW PRESSURE EXPERIMENTS.

There has been very little change noted in the fundus' appearance, but at the end of the rebreathing run of above 20,000 feet in the low pressure chamber the retinal vessels have shown some congestion.

IRIS REACTION DURING REBREATHING AND LOW PRESSURE EXPERIMENTS.

The object of these tests is to determine the change in reactions of the iris and pupillary diameters during rebreathing.

Fifteen men were examined for this experiment and carried from 18,000 to 28,000 feet. The changes were not altogether uniform, as certain of the cases reacted more strongly to light than to accommodation, and vice versa. Some changes, however, seem to be fairly constant.

Below 10,000 feet no changes are noted; above this, varying in different individuals as to height, there is an increase in reflexes for both light and accommodation. This holds until late in the experiment and then slowly diminishes, and if the subject is allowed to remain on the machine near fainting point, reflexes are entirely abolished. The pupil slowly dilates, usually beginning above 15,000 feet and remains so during the remainder of the experiment. If allowed to remain on the machine too near the fainting point, the pupil is quite widely dilated.

EFFECT OF TOBACCO UPON THE EYE.

The problem, as taken up by the Ophthalmological Department of the Medical Research Laboratory, Hazelhurst Field, was to determine what effect, if any, tobacco has upon vision, reaction time, retinal sensitivity, accommodation, and convergence of habitués, and nonsmokers. Although this investigation is still uncompleted, it is believed that a preliminary report is desirable.

The widespread, increasing, and unrestricted use of tobacco in the Army and Navy furnishes the practical incentive and justification for the investigation.

APPARATUS EMPLOYED THUS FAR.

A. For visual acuity: (1) Ives apparatus at 20 feet. (2) Snellen test card. (Unsatisfactory and abandoned for this purpose.)

NOTE.—20/20 vision is equivalent to 1.00 on the Ives apparatus.

B. For circulation effects: A standard sphygmomanometer, stop watch, and stethoscope.

C. Accommodation and convergence (near point): The Prince rule, with Jaeger test type, and a 2-millimeter black dot on a white field.

D. Retinal sensitivity and contract sensitivity: For these, the photometric wedge was used, employed in such a manner as to blend within a period of 5 to 8 seconds, two gray squares, one within the other, differing from each other in tint by 13 perceptible shades. The squares must be highly illuminated by a shaded nitrogen daylight lamp, and observed at a distance of 20 feet.

TESTS.

Visual acuity: This was very carefully taken on the Ives apparatus every four minutes during smoking, after having previously taken several preliminary observations at two-minute intervals. Where possible, control tests lasting a half hour or more were taken later in order to compare the regularity of the curves with those of the tests while smoking. Several observations were made after the subject had ceased to smoke.

In all cases vision was taken separately for each eye, with the subject wearing his usual correcting lenses. Variation of the direction of the lines in the Ives apparatus was tried but was discontinued as unsatisfactory and the lines were maintained in one position during the test (generally vertical). This was to avoid variation in readings due to slight astigmatic errors.

Blood pressure.—This was taken every four minutes after at least three preliminary observations, two minutes apart, and was con-

tinued until the cigar was consumed with one or more final observations, two to four minutes afterwards. The systolic and diastolic pressure was taken by stethoscope method.

Pulse.—Normals and test observations at four-minute intervals.

Convergence and accommodation.—These were taken generally every 10 minutes, as was also retinal sensitivity to contrast.

Results.—Of 16 subjects tested and their records charted and curves plotted, results are as follows:

A. Visual acuity: Twelve (75 per cent) showed a fall, the average of which was 0.17 (Ives's apparatus).

One (6 per cent) showed a rise; three (19 per cent) not changed.

NOTE.—Curves showing both a rise and a fall are classed according to which predominates. A slight preliminary rise occurred in nine cases, the dominant effect of which, however, was a fall. The duration of lowered vision was very brief, lasting at most only a few minutes after cessation of smoking.

B. Systolic and diastolic blood pressure: Both were affected and in general similarly, though not in equal degree. Both showed a rise of 69 per cent in 16 cases. In 3 (19 per cent) there was a fall of the systolic and 4 (25 per cent) of the diastolic pressure. The average rise of the systolic was 9.3 millimeters, of the diastolic 7 millimeters. The average fall of the systolic was 8 millimeters, of the diastolic 5.5 millimeters. Here also the effect was temporary, usually lasting but a few minutes.

C. Pulse: A rise in pulse rate was nearly constant, 14 cases out of 16 (87½ per cent) showing an increase, the average of which was 14.3 beats per minute. Two cases showed a fall averaging five beats.

D. Accommodation: Of 13 subjects, 5 (38 per cent) showed a loss, this loss averaging 33 millimeters. Two showed an improvement averaging 12 millimeters; 6 (46 per cent) showed no change. Those showing the greatest loss were presbyopic.

E. Convergence: Of 12 cases, 50 per cent showed more or less falling off; 5 (42 per cent) showed no change. One apparently improved by 10 millimeters. It will be seen that the effect upon convergence and accommodation was much more uncertain than in the cases of visual acuity and blood pressure. The same may be said for superduction and adduction as tested by prisms.

F. Retinal contrastivity: The use of the ——— wedge elicited no changes under tobacco, so far as could be ascertained, except in two cases, which showed a loss of 10 millimeters.

Conclusions: Observations to date indicate that approximately 75 per cent of smokers have definite though temporary effects upon vision from a single cigar, and almost an equal proportion show a rise in blood pressure, while there is an increased pulse rate in nearly

90 per cent. This effect is also temporary, although John, in 1913, reported that the use of two cigars caused a rise of blood pressure lasting for two hours after the cessation of smoking. In 1907 Hesse found similar pressure effects. Nonsmokers have not as yet been tested in numbers to afford a report. Only one enters this series. He showed a fall of 0.3 in visual acuity. Accommodation fell off 15 millimeters. There was apparent reduction in retinal contrastivity of 1 millimeter. Some giddiness occurred at 18 minutes from start, accompanied by slight nausea.

Aviation medical authorities in the war zone have remarked that aviators were using tobacco excessively, smoking while in the air as well as incessantly while on the ground. It has further been reported that soldiers on the western front have frequently complained of night blindness. Some of these cases may be due to excessive tobacco without the occurrence of a typical tobacco amblyopia. Practically the same results as have been obtained by smoking one cigar have been produced by the inhalation of one or two cigarettes.

VI.—PSYCHOLOGY DEPARTMENT.

I. THE RELATION OF PSYCHOLOGY TO THE AVIATOR.

The function of psychology in respect to the aviator is to study his adaptability to the work required of him. Assuming that the determinable structural qualifications of the aviator are adequate, that his more mechanical physiological functions are satisfactory, it is yet necessary to determine the conscious or integrative action of his organism, with regard to the adaptations which contribute to the composition of a good flier; and further, his adaptability to one or another set of requirements for different departments of the flying work.

Obviously, these determinations may be made by the trial and error method (which in this case is merely a survival method), and this has been followed to a large extent in several foreign air services. The candidates are roughly selected, and those who do not successfully adapt themselves to the general or specific requirements practically eliminate themselves. This method is, however, believed to be wasteful, and undoubtedly a more economical method can be successfully followed.

The contribution which psychology can make to the efficiency of the Air Service, in view of the foregoing, can be summarized under eight heads:

1. The adaptability of the individual to the general requirements of the service may be determined. Some of these requirements may be enumerated in a list not intended to be exhaustive.

I. Perception (including discrimination). The ability to perceive accurately and quickly through the various senses (visual, auditory, tactile, muscular and articular, and visceral), which are important for the flier, depends not merely on the perfection of the sense organs, but also on the integrative action by which definite and useful perceptual reactions are achieved.

II. Control of "voluntary" activity, i. e., of that activity which must vary in its expression according to the variations in the environment. Such activity is truly integrative and is in general a part of the perceptual process.

III. Maintenance of equilibrium, and orientation. The complex mechanism by which the flier preserves his balance, and the more complex mechanism by which he finds his way about, are so interconnected that they necessarily must be treated together, although the functions are widely different. To a large extent these functions are automatic (mechanical), yet both involve all the senses enumerated above and involve in both cases more or less integration of the nervous system.

IV. Memory (in the sense of retentiveness) is dependent on conditions which are apparently in part constitutional, and in part subject to control, although the detailed basis of these conditions is not at present known.

V. Associative thinking, which depends on retentiveness and expresses itself in the various forms of judgment, inference, and decisions, is an integrative function closely connected with perception, but by no means varying directly with it in efficiency. It is becoming more and more clear that thinking, like perception, is a conscious reaction of the organism, and can be adequately treated only as such.

VI. Emotional response: Emotions are directly connected with the driving force of the organism, and are in the highest degree important in all mental processes. The Darwinian point of view of emotion (as developed by James, Sutherland, and especially by Lange), that it is a bodily (chiefly viceral) condition or process, is more and more becoming indispensible for practical consideration of the emotional life.

VII. Attention, which is the direct expression of the degree and completeness of integration, is of especial importance. Not only the extent to which the flier can subordinate all other reactions to the vital reaction of the moment, and the length of time during which the vitally important details of the situation which confronts him can continue to dominate his nervous system in spite of distractions (the power of sustaining attention, as we commonly express it); but also the proper balance in integration (the power of attending efficiently to several distinct details in a situation), need to be studied very carefully.

VIII. Habit formation, or learning, which is the modification of the integrative system (it may be the modification of perception and motor control, or of thinking process), is a topic of especial importance in flying and is one concerning which psychologists have acquired a large amount of information in recent years.

A knowledge of the precise requirements for the flier in all these directions is yet to be obtained. Various opinions have been expressed as to the requirements, but psychologists are unanimously of the opinion that any conclusions in these matters should be reached by systematic observations and experiments. In this laboratory work on these problems is being carried on by men who have so far attained results which are distinctly encouraging, but not yet in a stage where the communication thereof is feasible.

2. The adaptability of the aviator to special requirements of the different departments of flying work: The same work is not required of observers as is required of pilots, and bombing and combat do not require exactly the same sort of pilot work. The list of special qualifications will probably grow, as aviation develops, but so far little has been done in the way of determining and measuring the special qualifications. Work has been undertaken in this line and results will be forthcoming in due time.

3. Special conditions to which the flier may be subjected: Probably the most important special condition is the combination of cold and low oxygen tension encountered at high altitudes. While nothing has yet been done in the Medical Research Laboratory on the temperature problem, a great deal has been done on effects of insufficient oxygen supply. In addition to the physiological effects of asphyxiation, there are distinct psychological effects which have been carefully studied by the psychology section. Although we have recognized from the beginning that tests for asphyxiation effects, and the grading of fliers on the basis of their endurance of oxygen deprivation, are of minor importance as compared with tests in the other directions indicated above (since the evil effects of the low oxygen tension of the upper atmosphere can in most cases be obviated by administering oxygen to the flier), nevertheless it was necessary to get this problem out of the way before other problems could be attacked. Full details of the psychological tests and ratings for oxygen shortage are given in a later chapter.

4. Deterioration: Assuming that the individual flier is fit for his job and properly trained, we nevertheless find that he may suffer deterioration, both of a temporary sort and of the more lasting sort, which is frequently designated as "staleness." The fact that an individual when in his best trim is a high-class flier and efficient in his especial department of flying does not promise that he will re-

main such; the fact that an individual shows high capacity for endurance of oxygen shortage does not signify that he is in good flying condition, although it is known that deterioration in certain conditions requisite for flying will reduce the individual's ability to withstand oxygen shortage.

Although it is believed that in certain cases psychological causes (worry, fear) may be responsible for deterioration, there is probably a more important range of physiological causes operative. In all these cases, however, mental symptoms are produced, since it is precisely in the failure to integrate properly rather than in specific failure of sense organ or muscles, that "staleness" shows itself. The discovery of the symptoms and the development of tests which shall reveal them as early as possible is undoubtedly one of the most important contributions psychology can make to aviation, since it is important that the symptoms be detected in the earliest possible stage. The task is being undertaken, and we have reason to be confident it will be successfully carried out if the work continues.

From the foregoing presentation it should be evident that a number of diverse problems confront us. The requisite tests of general ability and of special abilities must be worked out conjunctively, but are not capable of combination. Certain of these tests which are capable of repetition may be useful in determining an aviator's condition (for detecting deterioration), but the applicability of these or any other tests for deterioration must be worked out independently. It is especially important to note that psychological tests for endurance of special conditions (oxygen shortage), if adequate for their purpose, can not give any reliable evidence on general or other special qualifications or on deterioration.

II. PSYCHOLOGICAL RATING OF AVIATORS FOR ALTITUDE LIMITS.

OUTLINE OF CONDITIONS.

The work on oxygen deficiency has so far been principally under the conditions established by the rebreathing apparatus, with some check experiments in the low-pressure chamber. With this apparatus it is possible to produce the oxygen tension in respired air equivalent to the tension for any elevation up to that at which the patient can no longer endure the deficiency.

The chief respiratory differences between the rebreathing conditions and those actually obtaining in the upper atmosphere are (1) the greater density, (2) the greater moisture (practically saturation), (3) the higher temperature of the air in the rebreathing machine, and (4) the method of breathing, through the mouth, with the machine. While it is possible that one or another of these differences (most probably the third) may make a difference in the

case of prolonged holding of the patient at certain altitudes, for rapid "ascents" (i. e., passages from normal to low oxygen tension), the first two differences do not seem important. There has been as yet no means of testing the contributory effect of temperature, and it has not been possible to make a sufficiently thorough comparison of the effects of rebreathing with those of the low-pressure chamber. The discomfort of the mouth breathing is undoubtedly important in individual cases, and hence interferes somewhat with the adequate rating of the aviators, but in the cases of experienced subjects is a minor matter and has no important bearing on the scientific conclusions.

PSYCHOLOGICAL EFFECTS.

The psychological effects of oxygen deficiency.—The effects of oxygen insufficiency upon the psychological process have been from the beginning of our work studied empirically, with the least possible hypothetical guidance. A wide range of details of mental life have been investigated, the order and method of investigation being practically directed by the working tests which were available or which we have been able to devise. Hence our results are capable of throwing a light on the fundamental principles of psychology.

These results square distinctly with the conception of psychological processes as integrative, i. e., as dependent on the integration of the central nervous system, the working together of the system as a whole, rather than on the action of any specific parts of the system.

The basic and important psychological effects of asphyxiation are on voluntary coordination and attention. Until asphyxiation reaches the stage in which the integrative mechanism is rapidly approaching the condition of complete unconsciousness, no effects are demonstrable which are not clearly the failure of the one or the other, or both, of these two mental factors. In the prefinal stages perception is as efficient as the muscular control of the sense organs and organs of expression and the power to attend to the stimuli permit. Discriminative judgment, likewise, shows no falling off in rapidity or accuracy except as impaired motor control and attention produce it. Memory, with "immediate memory," as tested by the ability to produce what has been perceived or learned immediately before, and "true memory," as tested by the ability to produce something which has been "latent" for a certain interval after being learned are apparently not affected except as the inability to attend to the details in learning or in reproducing or inability to control the muscular mechanism of expression may enter.

The efficiency of limited neuro-muscular groups, as indicated by dynamometer tests, is not impaired in the prefinal stages of asphyxiation.

As instances of tests involving perception and discrimination, we may cite the copying of a list of work and the translation of words into code. In both of these cases speed and accuracy are maintained up to the final stages of asphyxiation, provided the muscular mechanism of accommodation and convergence are not seriously affected, although the mechanism for handwriting may be so affected that the written results of the list are legible with difficulty.

In more complicated discrimination, where rapid and accurate recognition and classification of material are required, the results are similar. Ability to remember and to chart correctly the relative spacial position of objects remains normal within the limits of ability to make adequate movements of the hand in charting.

It is interesting to note that the sensitivity and acuity of the sense organs shows no consistent impairment and that apparently the speed of simple reactions (the simple reactions do not in general require a high degree of integration) is not intrinsically reduced. More work remains to be done on simple reactions, however, before definite statements can be made. The distinctive effect on the nervous system, in short, seems to be a change in its integrative action and not a change in the irritability or efficiency of any particular part or unit. In this respect the whole picture of asphyxiation from a psychological point of view is strongly suggestive of the picture of progressive alcoholic intoxication.

There is some evidence that practice in enduring asphyxiation has value in increasing the efficiency of the individual under a certain degree of asphyxiation. Expressed in untechnical terms, the individual may learn to husband his resources and by applying his capacity to the tasks in hand accomplish more at a certain level than he could without practice. More definite statement on this point can not be made on the basis of the present material. It is not possible that habituation to the effects of alcohol (not to regular dosages) may be a help in acquiring ability to maintain motor and attention efficiency in certain degrees of asphyxiation.

Training of another sort may also be advantageous. "Grit" counts in the maintenance of efficiency, or rather the maintenance of efficiency in the face of serious oxygen deficiency is "grit," and if "grit" in one task or situation can be acquired or increased by training in other situations (which is by no means certain), then such training is advantageous.

PRACTICAL REQUIREMENTS.

Under the practical requirements of rating, tests must be single and brief during progressive depletion of the oxygen supply. If many individuals are to be examined it is not practicable to spend even several hours on each one. Hence it is not possible to hold the

subject at a moderately high altitude so that asphyxiation effects will eventually appear. Nor is it possible to repeat a briefer test a number of times. Hence, the subject must be allowed to rebreathe rapidly (during not much over a half hour at most), to a low point of oxygen tension, reaching his maximal altitude for that rate of "ascent." It follows that the method used must be one which is not approved for psychological work under other conditions and which, for want of a better term, is called clinical. Thus, since the subject's condition is rapidly changing from minute to minute, the examiners must be able to determine the psychological condition at any minute and can not use the method (more exact under other conditions) of determining the average speed and accuracy of work done during a period of several minutes.

A final composite reason for using a clinical method comes from the need for rapid work. Graphic methods might be employed, but would largely hinder the expedition of the work on account of the time and labor needed for their interpretation. Moreover, in such rapid work fineness of gradation in rating would be seriously misleading, hence the greater exactness of the graphic method would be largely illusory. For research purposes, on the other hand, the matter is entirely different.

Fatigue, also, must enter into the test as little as possible, else the deterioration in performance due to fatigue will confuse the determination of the asphyxiation effects.

Since the test can not be repeated, it is important that there shall be little practice effect in the work required, else the individual variation in rates of learning will prevent the fair determination of the relative susceptibility of the different subjects to the oxygen deprivation, which is the sole point to be considered.

It was early discovered that under asphyxiation, as under alcoholic intoxication, it is possible for a reactor to "pull himself together" for a brief space of time (a minute, or even several minutes), during which his efficiency on a set task may be as high as (or even higher than) his normal, at the termination of the task sinking to a relatively low level of efficiency. If given a series of tasks, with brief resting intervals between, the reactor may therefore accomplish a performance which is practically normal, even up to a minute or two before the point at which complete lapse of integration occurs. In this way his real psychological deterioration may be masked. It is necessary, therefore, to set a task which, although minimally fatiguing, is practically continuous, allowing the reactor no expected periods in which no work will be demanded of him, and thus preventing him from making use of attention peaks as the phases of "pulling himself together" may justly be called.

In determining the sensitivity or acuity of sense organs, on the other hand, the "attention peaks" are precisely in order, and pause should be taken to present the stimuli at the highest peaks.

Many tests which otherwise would be applicable impel the subject (reactor) to hold his breath during the crucial moments of the test. The conventional steadiness test is of this character. If the reactor, already suffering from oxygen deficiency, holds his breath for 20 seconds, or largely reduces his breathing during that period, he makes an important change in his oxygen supply, a change, moreover, which can not be measured. Hence the purpose of the test is largely defeated. The steadiness test, and others in this class, which may show marked effects of low-oxygen tension, can not be used.

Although it is desirable that the test employed shall in some degree correspond to the aviator's actual task in flying, it is important that it shall not use any of the movements or discrimination involved in flying, else it would be impossible to rate fairly both those with and without experience in planes.

A final composite reason for using a "clinical" method comes from the need for rapid work. Graphic records might be employed, but would largely hinder the expedition of the work on account of the time and labor needed for their interpretation. Moreover, in such rapid work fineness of gradation in rating would be seriously misleading, hence the greater exactness of graphic methods would be largely specious. For experimental work the matter is entirely different.

In addition to general limitations of method and apparatus due to necessary working conditions, there are specific limitations imposed by the rebreathing apparatus and the cardiovascular work which must be simultaneous with the psychological.

I. The reactor can not speak on account of the mouthpiece. This excludes such tests as the association reaction, which otherwise might be highly useful.

II. The reactor's head movements are narrowly limited and his field of view correspondingly restricted. This is not a very serious limitation.

III. The blood pressure, which is taken throughout the test, is taken from the reactor's left arm. This further limits the reactor's means of expression to one arm and his feet.

APPARATUS FOR THE STANDARD TEST.

The apparatus used for the psychological tests consists of two groups, (*a*) and (*b*). The (*a*) group includes a number of pieces assembled on a specially designed table, adjustable in height and slope, and swinging on a single heavy post mounted on a cast-iron base. This table is designed to furnish a sufficiently rigid mounting

and at the same time give greater convenience than could be afforded by a table with legs.

(*a*) The apparatus mounted on the table form three separate units, (1) a series of 14 stimulus lamps (2 c. p.) arranged in two rows of seven each, with two similarly arranged rows of contact buttons; each surrounded by a washer; a green check lamp and a red error lamp; and a stylus with a hard rubber handle and metal tip. These parts of the unit are so wired electrically that when a stimulus lamp lights the corresponding contact button is "alive," and if touched with the metal tip of the stylus causes the check lamp to light. If the washer surrounding any of the buttons is touched with the stylus at any time, the error lamp lights.

(2) Two ammeters mounted on a metal arm above the table top are connected in series with two rheostats, one on the upper side of the table top at the edge nearer the reactor, the other underneath, at the edge nearer the psychologist. One ammeter faces the reactor, the other the psychologist. A change in the resistance made by the psychologist at his rheostat, causing a change in the ammeter reading, may be compensated for by a change in the reactor's rheostat, by which the original ammeter reading may be restored.

(3) A small electric motor mounted on the upper side of the table top is connected in series with a third rheostat underneath the table. A two-way lever switch mounted underneath the table at the edge next to the psychologist and a rocking pedal two-way switch on the floor under the table are connected with the rheostat by a three-wire system, so that a part of the resistance of the rheostat can be cut out (thus increasing the speed of the motor) by either switch and again cut in (thus restoring the lower motor speed) by either switch.

(*b*) The second group of apparatus, on a small table in any convenient part of the room, consists of either a button board having 14 buttons, corresponding to the 14 stimulus lamps, or of an automatic distributor which lights the stimulus lamps in selective order and times their duration. With the button board an automatic flash timer may be used, requiring an assistant merely to select the buttons, or the assistant may time the flasher with a stop-watch as well as select the buttons.

The (*a*) and (*b*) groups of apparatus are provided with transformers to adapt the electric current to the 2 c. p. lamps, and are electrically connected with either and with the source of 120 volt a. c. current by flexible cables.

Method of conducting the test. The rebreathing machine should be adjusted by the physiologist to give a "standard run," which will vary in time according to the individual and his method of work, but which will bring a reactor of the A class to 7 per cent of oxygen

in 25 minutes on the average. For this standard run the quantity of air in the tank at start is 60 liters.

The reactor, being seated in proper position before the (*a*) apparatus, is given the following instructions in printed form:

INSTRUCTIONS.

READ CAREFULLY.

You have three things to do:

1. *Lights.*

When a light flashes, touch with the stylus the top of the corresponding button. Do *not* touch the washer.

2. *Ammeter.*

Watch the ammeter and by adjusting the slide of the rheostat (using the right hand) keep the ammeter at the designated mark.

3. *Motor.*

Keep the motor at low speed by maintaining the proper positions of the pedal. When the motor speeds up, push the pedal from whichever position in which it may be (heel down, or toe down), into the opposite position, and leave it in the new position until the speed again increases.

NOTES.—(*a*) The lights are of first importance, i. e., if a light appears when you are reacting (or about to react) to the ammeter-hand, react to the light first and then go back to the rheostat.

(*b*) When you touch with the stylus a contact-button corresponding to a light, the movement of hand and arm should be a "free" one (neither arm nor hand should touch table, rheostat, or board). The hand may, at other times, rest on the slide of the rheostat.

(*c*) Do your work with ACCURACY, NEATNESS, and PROMPTNESS. Do not bang, slam, or jab.

While the reactor is reading the instructions, the psychologist is ready to explain any detail of the apparatus or method in which the reactor may show interest; and after the reactor has finished, the psychologist further explains the procedure and verbally emphasizes the important points in the instruction.

When the rebreathing machine is ready and the blood-pressure recorder has secured the requisite preliminary readings, the mouthpiece and nose clip being in place, the external opening of the mouthpiece is closed by the responsible clinician and the test commences. The psychologist and all others concerned in making the test start their stop watches at the moment when the rebreathing commences. The psychologist should record if possible the time which elapses between the insertion of the mouthpiece and the commencing of the breathing, unless a regular routine for this time be adopted.

During the first three minutes of the test the psychologist coaches the reactor if necessary and estimates his comprehension of the task

and instructions, his power of attention, and his composure (freedom from excitement or nervousness), entering these on the record sheet then or later as good, fair, or poor. He should also note the motor tendencies of the reactor, and if these fall in one or more of the following categories this also should be entered.

MOTOR TENDENCIES.

To be put on original record sheet *at bottom;* on official sheet under *general impressions, psychological;* on psychology record card under *notes:*

(1) Tremor.
(2) Tense.
(3) Impulsive.
(4) Steady.
(5) Rapid.
(6) Slow.
(7) Hesitant.
(8) Accurate.
(9) Inaccurate.
(10) (Combinations of above.)

Enter merely the appropriate type word or words; it is not necessary to write "motor tendencies."

In addition to these general tendencies, it is important that the psychologist take notice of the specific tendencies shown by the reactor, and if definite types of error are shown, watch during the succeeding five or six minutes for improvements in these details. In this way the "M" and "A" determination described below may be accurately noted as deterioration from the normal proficiency of the reactor, and not as failures with regard to an absolute standard. This is important, since the rating on these tests is valid only as an index of the effects of asphyxiation and not as an index of efficiency or inefficiency in any other respect. The comprehension, attention, composure, and motor entries are, however, worth recording in order that this data may be used later for purposes other than oxygen rating.

Normally the test continues until complete inefficiency is reached, at which point the psychologist must sharply notify the responsible medical attendant in order that the reactor may at once be given air, and so prevented from undergoing the collapse which would ensue in a minute or so.

The recognition of complete inefficiency is a matter on which the psychologist must carefully train himself. In general it shows in a definite way, as described below, but may show in forms which are readily recognized by the trained observer but described with difficulty.

In many cases the responsible medical attendant will find it necessary to stop the test because of dangerous cardiovascular symptoms before inefficiency is reached.

In commencing work on the reactor it is advisable to allow him to react to the lights alone during the first minute and add successively the changes in the motor noise and in the ammeter readings. He should be working on all three tasks by the middle of the third minute.

In observing, the psychologist needs to attend as constantly as possible to the behavior of the reactor, and hence must reduce the labor of recording to a minimum. For this purpose and for the purpose of standardizing the method of observation the following symbols have been adopted:

SYMBOLS AND THEIR SIGNIFICANCE.

→	Rebreathing starts.
W	Work begins.
$\overset{m}{\mathrm{V}}$	First significant effects on "voluntary coordination."
♀	"Fumbling"; clumsy; inaccuracy in touching targets.
ʔ	"Groping"; approaching target with corrective movements. Usually a compensation for ♀.
E	Increased "effort" or force in applying stylus to targets.
Ǝ	Decreased effort.
I	"Impulsive" or uncontrolled movements: a, on the outward movement; to the target. b, on the return movement.
S	Slowing of reactive movements.
F	Speeding of reactive movements.
$\overset{a}{\mathrm{V}}$	First significant effects on "attention."
dl	"Distraction" from lights, neglects lights.
dl-v	Neglects lights for voltmeter.
/	(Contraction for dl I.) Reactor delays initiating stylus movement so long that he fails to light check lamp.
//	Reactor delays so long that he touches the target after light has gone out.
///	Reactor starts movement after light has gone out.
////	Reactor makes no attempt to initiate light reaction.
dv	"Distraction" from the dial; neglects to note and adjust the position of the index hand.
dn	"Distraction" from the noise; neglects to control the speed motor.
/Cl/	Confusion between rows of lamps; but finally touches the right target.
$\overline{\underline{\mathrm{Cl}}}$	Confusion between columns of lamps; but finally touches the right target.
/$\underline{\mathrm{wl}}$/	Selecting target in wrong row.

wl Selecting target in wrong column.
Wv Wrong direction on the dial.
WN Wrong shift of pedal.
◈ Two of the symptoms, ♀, ?, I, and E, repeatedly. In certain cases, exaggeration of *one*.
◈ Two of the symptoms, dl, dv, dn, ///, /Cl/, Cl, Zv. In certain cases, exaggeration of *one*.
O "Inefficiency." Inability to control any of the three tasks. The reactor sometimes stares at the lights without making any attempt to touch the target; or makes merely irrelevant touches. Completely disregarding L and N. Sometimes he develops severe tremors or jerks which render it impossible to work. Occasionally a reactor develops unique symptom at this point.
* Breakdown. Reactor ceases to work and commences to collapse. This comes very soon (30″ to 2′) after 0; is qualitatively a much more serious condition.
X Reactor "taken off." Air or oxygen given him.

ADDITIONAL SYMBOLS FOR SYMPTOMS WHICH MAY BE OF DIAGNOSTIC AID.

∿∿ Tremor of the hand.
⋀⋀⋀ Jerkiness of the hand.
H Swaying or drooping of the head.
T Taps button more than once.
R Rests hand or fingers while touching button.
K Keeps stylus on button after making touch.

In general, the "arrowheads" (→) and "diamonds" (◇) are not inserted until after the test is finished.

On the completion of the test the entries on the record sheet are completed, and the material is now ready for rating, which is done on the following basis:

RATING SCHEME.

1. Take 25 minutes as the standard duration of a run. If the O or X appears before the end of 25 minutes, debit one point for each minute; similarly, credit one point for each minute in case O or X appears after 25 minutes.

2. Assume as a standard of altitude 7 per cent of oxygen for O or X. Debit or credit one point for each $\frac{1}{10}$ of 1 per cent.

3. As in the case of 1, take 25 minutes as the standard time for the appearance of both of the two diamonds. Debit or credit one point for each minute as above.

4. Assume 15 minutes as the standard time for the appearance of both the two arrowheads. Debit or credit for each minute as above.

5. If the record of the subject tested be such that either arrowhead or either diamond can not be entered, compute the symbol in question as if it fell at the point of O (or X, if O be not reached; see paragraph 6, below).

6. Add the debits and credits, and assign to class as follows:

+n	0	Class A+
0	−12	Class A−
−12	−30	Class B
−30	−n	Class C

7. Where an oxygen tension of 8 per cent or less is not attained in less than 30 minutes, a grade above B shall not be assigned. For runs reaching a low percentage (below 7 per cent) in less than 22 minutes, discretion may be exercised in debiting for earliness of symbols. Such short runs are especially to be avoided if possible.

8. For a definite rating O must be used. However, in case the test was stopped by the clinician without reaching O, the tentative rating may be computed from X. If this tentative rating is A, it is to be entered as such. If, however, the tentative rating is of a lower class, it is to be entered with the addition "or higher." This phrase "or higher" shall always indicate that the reactor was removed before reaching (O), and not at the instance of the psychologist. It is not to be entered in any other case.

On first glance the rating scheme seems to be based on time rather than on oxygen percentage, but this is only apparent. If every reactor was run through at the same rate, for example, a rate of oxygen depletion at which 7 per cent would be reached in 25 minutes, it would be immaterial whether the oxygen percentages or the times at which the arrowheads, diamonds, and circles are reached should be used, since there would be a fixed correspondence between these. Since rates vary in accordance with the individual rates of oxygen consumption, and since a faster rate enables the reactor to reach a lower percentage, and a slower rate brings inefficiency at a higher percentage it is necessary to make allowance for the variations in rate. This can be done either by computing in oxygen percentages, and then making a correction for the time, or more simply, as in the scheme actually employed, by computing in times, as if the oxygen change followed a line of the same slope in each case, and then correcting for deviation from this slope in terms of the final oxygen percentages reached.

The rating scheme is adequate to classify the reactors in the four groups (A-plus, A-minus, B, and C), provided the psychologist who does the observing also does the rating, and exercises due judgment, based on his general observation of the reactor's work, in rating those

cases which lie near the limits of the several classes. The scheme should be an assistance to the psychologist's final judgment, not a hampering condition, although the most satisfactory results will be obtained by relying on it very substantially.

The chief difficulty with this method of testing is in the heavy and exhausting labor entailed on the psychologist. Necessarily his attention is kept at a high level throughout the test, and it has already become evident that a full daily program will not be possible as a continuous thing. It is hoped that it will be possible to supply two psychologists with each testing unit of which heavy duty is required, in order that they may relieve each other and maintain the efficiency of the unit.

In making the test, diligent care must be exercised to prevent the reactor from being anxious or alarmed as to the experience he is to undergo. Hence no remarks must be made in his presence as to danger or serious discomfort, and, if necessary, assurance should be given that the test makes no great demands on the reactor. It is also important that instructions be given in a routine way, the same for all reactors; otherwise the purposes of the test as a relative rating scheme are in part defeated.

The temporary physical condition of the reactor is also a matter which should be carefully considered. Loss of sleep, worry, dissipation, or other causes which reduce general resistance are apt to reduce the capacity for endurance of oxygen deficiency, and produce an earlier onset of psychological inefficiency than would occur under better conditions.

On the other hand, the reactor may be in bad shape physically or mentally (from worry, etc.) and yet make a very good record. One reactor, for example, who made an unusually good record, with fine motor control and efficient attention down to a low percentage of oxygen, had had but a few hours sleep in 48 hours, felt in "rotten" shape, and expressed himself anxious to come back when he felt better, "to see what he really could do on the test."

In short, the test gives a measure of endurance of oxygen deficiency solely, and while this endurance may be affected by a variety of factors, it gives no measure of these factors.

Some incidental results of the work on rebreathing.—It is apparent that a great deal which has come to light in the course of the work will be of value for work more or less closely allied. Findings in regard to the precise effect of oxygen shortage, and the concealment of these effects through "attention peaks" point to an application, with a possibility of clearing up certain puzzling results of earlier work. The same application may be made in studies of fatigue, in which in the past no great success has been attained with psycho-

logical tests. Alcohol and drug effe
in the light of the present work.

The relation of certain emotional
also appeared in an interesting way
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III. THE PSYCHOLOGICAL (

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mine the applicability and usefulness of the tests. In some cases the development of the test itself is a difficult experimental undertaking; in other cases the tests are easily obtained, requiring merely the application and correlation.

Evidence of flying ability is obtained, for the purpose of comparison with the results of the tests, from the men who have trained the fliers tested, and have observed their individual progress in the work of aviation. The value of any test of a specific function which may be important for aviation must ultimately rest solely on this comparison. No theoretical considerations of the qualifications of a flier can be substituted for the empirical determination of the relative flying abilities of men differing in respect to the qualifications in question.

Experimental work on the problem of flying qualifications has been done at San Diego and Berkeley and is in progress in this laboratory. Some of the points attacked are:

(1) Reaction to auditory, tactual, and visual stimulations, and to changes of position of the body: The time required for reaction to the stimuli of the sorts mentioned is measured, and the individuals are rated on their average reaction times of each sort, and their variability. While nothing important is to be expected to result directly from the measurement of the simple reaction times to sound light and touch, even the negative finding, if it occurs, is important.

(2) Discrimination time: The time required to discriminate accurately between different stimuli suddenly presented.

(3) Association reaction time: The time required to reply to a spoken word with another word which is related to the stimulus word in a prescribed way. For example, nouns may be given and the reactor required to respond in each case with an adjective appropriately modifying the noun; or verbs may be given and the reactor required to respond to each with the name of an object appropriate for the action indicated by the verb. In this work the time is measured and the appropriateness or accuracy of the response is evaluated as well.

(4) The rate at which a person can learn a certain complicated muscular coordination involving the hands and feet in somewhat the way required in piloting a plane.

(5) The sensitivity to gradual changes in the position of the body in horizontal and vertical planes. Several important researches are in progress on points connected with the analysis of the highly complicated psycho-physical mechanism involved in the maintenance of equilibrium.

(6) The capacity to acquire certain simple forms of dexterity.

(7) The temporal and other conditions of the appearance of the signs of fatigue.

There are also in progress experiments on orientation; the ability to find one's way about, and to know, from moment to moment and from position to position the direction and distances of important near and far features of the environment. This may readily be granted to be a topic of the highest importance for aviation, although the various tests which are being developed are not yet in the stage of application to aviators, by which application only, as indicated above, can the practical value of the tests be determined.

PSYCHOLOGICAL INVESTIGATIONS WITH LOW OXYGEN TENSION.

1. *Judgment.*—A test of judgment has been carried out under supervision by enlisted psychologists. On each of a large number of blank playing cards, a nonsense syllable was printed in large letters: PEL, GUJ, KIM, CEZ, etc. A card rack with five compartments (fig. 4) was made, into which stacks of the cards fitted conveniently. In the second compartment from the right, the shuffled cards were stacked, separated into groups of 13 by blank cards. Over the three compartments at the left, the following labels were pasted:

1.	2.	3.
JEL DIM	MAX FOD	TID LEF

The reactor was required to take the cards from the stack one at a time and file each card in the compartment under the label to which the syllable on the card had the greatest resemblance. For example, PEL belongs in the first compartment, having two letters in common with the first label, only one in common with the third, and none in common with the second label. Cards which belonged in none of the three compartments were to be filed in the compartment at the extreme right.

The psychologist took with a stop-watch the time for the sorting of each set of 13 cards, and signaled to the reactor to begin a new set every two minutes from the beginning of the test. By using a fixed "headway" in this way, the amount of work done is uniformly distributed through the series.

At the end of the series, the filed cards were checked for errors. Normal and rebreathing series were taken on 12 reactors. In the "normal" series, the reactor sat before the rebreathing machine, with the mouthpiece and nose clip in place, but breathing normal air. The typical results in one subject, showing the practice effect, and

lack of consistent oxygen effect up to the beginning of general psychomotor decline are presented in figure 5.

2. *Tactual discrimination.*—A test of tactual discrimination was carried out under supervision in the following way: Cards were prepared, each having a diamond-shaped hole cut in it in one of four positions (fig. 6). The card rack as described in the preceding experiment was used with a screen so arranged that the reactor could not see the cards nor his hands. Above each of four of the compartments of the rack was fixed one of the four types of cards and in view of the reactor. The cards to be sorted were shuffled, arranged in sets of 20, separated by blank cards in the fifth (right-hand) compartment.

The reactor was required to take the cards off the stack, one at a time, identify them by feeling them with the fingers, and file them in the proper compartments. Time was taken on the sets, and subsequent check of the sorted cards made for errors, as in the judgment experiment. "Normal" series on 10 men were conducted with the mouthpiece and nose clip of the rebreathing apparatus in place, but with the reactor breathing normal air, and other series taken on the same men while rebreathing. In this test no "headway" was used, the reactor commencing on another series as soon as one was finished. A typical result of the normal and rebreathing series on one man is presented in figure 7.

3. *Code test.*—A code test gave results similar to the foregoing tests, except that in the reading of the material to be coded adjustments of accommodations and convergence are important, and deterioration in these functions in some cases seriously affected the results.

8–B

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
H U M C B L Y E S I D K N A X W P T V Q R O J G Z F

K X B K P G S I Z R Y U L K E H Q X E G B D W V
O I X W T B A Y K E B D E G K G

FIG. 8.—Code test.

In this test, the codes used, and the material to be coded, were arranged on a series of cards as in figure 8, and these cards were presented in succession to the reactor, who was required to write the coded message in the lower part of the card.

4. *Dynamometer test.*—In order to find the effect of asphyxiation on the muscular force capable of exertion by limited systems, a series of dynamometer tests were run through. In these tests, the reactor was required to exert his maximal effort on a hand dyna-

mometer every two minutes. Normal and rebreathing series were taken on 10 reactors. Typical results on one reactor are presented in figure 9.

5. *Handwriting.*—In order to measure the effect of oxygen hunger at different barometric pressures, and the completeness of the restoration process attained by the administration of oxygen, a simple handwriting test was devised and carried out in the low-pressure chamber. A standard psychological vocabulary test of 100 words was used in making up the test cards. The 100 words of the standard vocabulary test were cut up and put in a hat and shuffled. As the words were drawn from the hat they were typewritten on a standard library card. By this method three test cards of 100 words each were obtained. The task of copying these cards offered the same difficulty to the subject since the same words were used on each test card only the order being different. Since the copying of words is an old-established habit, there was little improvement through practice.

The test was carried out as follows:

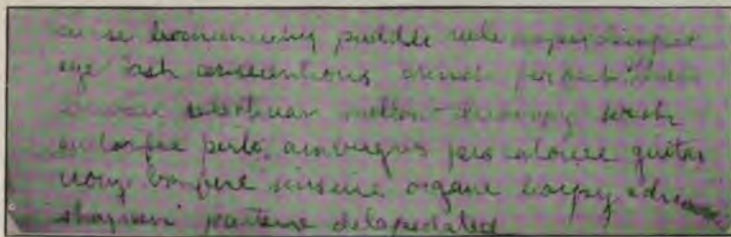
The subject was seated at a table in the tank. On a given signal the motor of the tank was started, but the pressure was not changed. The subject was handed card No. 1 and was asked to copy it as neatly, as rapidly, and as accurately as he could. As soon as this task was completed, the time of writing the card was taken. (This gives the normal record.) The signal for ascent (decrease in pressure) was then given. The ascent was made at the rate of about 1,000 feet per minute. After the subject had reached the given height he was kept at that level for 15 minutes with the motor running (to keep the noise constant). At the end of the 15-minute period at the given height the subject was asked to copy the second test card. After completing the copying, his time was taken as before. (This gives the oxygen-hunger record.) The subject was then given oxygen for two minutes and was then asked to copy the third test card. (This gives the oxygen-restoration record.) Upon the completion of the latter, the signal for descent was given.

The results from these handwriting tests were then treated as follows: First, they were measured (with reference to general form and legibility) on the scale for handwriting. This scale, as is well known, enables one directly to measure the quality of a given handwriting production in terms of certain units. For example, his normal might correspond to unit 12 on the scale; his oxygen-hunger record might correspond to unit 8 on the scale.

In rating the tests on the various subjects a penalty of 20 was attached for each unit lost on the scale. In addition to this rating on the scale, the following penalties were also imposed:

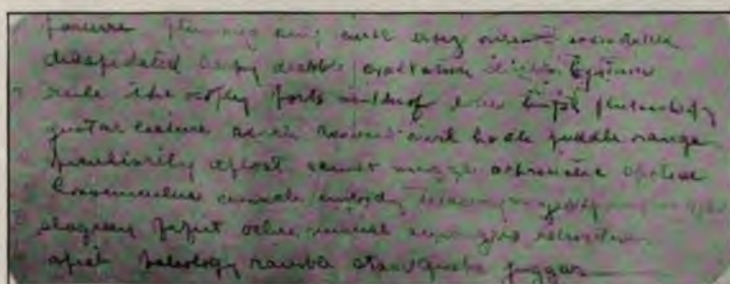
CAPT. BORING. (Fig. 10a.)

Handwriting, standard card—normal. 14,000 ft.



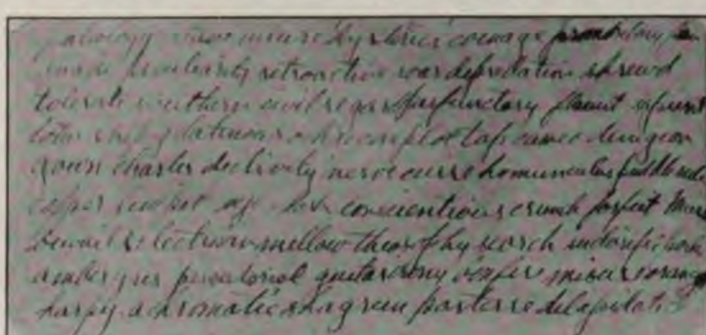
CAPT. BORING. (Fig. 10b.)

Handwriting, standard card—oxygen hunger. 14,000 ft.



CAPT. BORING. (Fig. 10c.)

Handwriting, standard card—oxygen restoration. 14,000 ft.



For each word omitted, a penalty of 2.

For each word misspelled or wrong word used, a penalty of 2.

For each word crossed out and rewritten, a penalty of 2.

For each word careted in, a penalty of 2.

For each word or letter thereof written over, a penalty of 2 each word.

Failure to follow line as well as original, a penalty of 2.

For each 10 seconds' increase in time over the normal, a penalty of 1.

For each 10 seconds' decrease in the time of writing, a credit of 1 was given.

It will thus be seen that errors in the normal are estimated as well as those made under oxygen hunger or after oxygen administration. A typical record follows:

Record of Pvt. Wickman, altitude 18,000 feet.

	Normal.	Under oxygen hunger.	Two minutes after administration of oxygen.
Legibility rated on scale, last 8 lines only (penalty of 20 for each unit lost on scale: credit of 20 for each unit gained)	0	− 80	0
Word omitted (penalty of 2 each word)	0	− 12	0
Word mispelled or wrong word used (penalty of 2 each word)	− 2	....	0
Word scratched out and rewritten (penalty of 2 each word)	0	− 2	0
Word careted in (penalty of 2 each word)	0	....	0
Word (or any part thereof written over, penalty of 2 each word)	− 4	− 6	0
Failure to follow line as well as original (penalty of 2 each line on last 8 lines)	0	....	0
Time, penalize 1 for each 10 seconds increase or credit 1 for each 10 seconds decrease	0	....	+ 3
Total penalties or credits	− 6	− 100	+ 3

These tests have been made at 14,000 feet, 16,000 feet, 18,000 feet, and 22,000 feet. While complete records are not in, the results so far obtained show that at 14,000 feet the effect of oxygen hunger is exceedingly slight (see fig. 10); at 16,000 feet the effect is scarcely more noticeable; while at 18,000 feet, on some subjects, at least, the effect is extremely marked (see fig. 11, the same subject). The handwriting—in some cases—becomes difficult to read, whereas other errors in spacing, following the line, omission of words, etc., are very marked. At 22,000 feet the first two subjects fainted, and it was not possible to continue the experiment. So far only one record has been obtained at 22,000 feet (fig. 12).[1]

In every case, except those where heart dilatation and fainting occurred, the 2 minutes' administration of oxygen completely restored the handwriting to normal.

[1] It should be noted that the altitudes are given by altimeter readings, and should be considerably increased if allowance is made for the difference in temperature of the air in the tank and that corresponding to the same pressures in the upper atmosphere.

It was planned to continue this experiment by the same method with the machine-gun camera and with a telegraph recording outfit, and to obtain and contrast a similar set of records on the rebreathing tank and the refrigerated pressure chamber. It was thought that the results on the handwriting test, the machine-gun camera, and the recording telegraph would give a tangible picture to the aviator of just what difficulties he would meet with in the air in writing messages, in sending them, and in the accuracy of his machine-gun work, and how these difficulties could be overcome by the use of oxygen.

6. *Memory.*—Various tests on memory were employed. For immediate memory, series of from 5 to 12 consonants are numbered, and series of from 2 to 5 observations, each made up of a color name and a number, were employed. Samples of the consonant series and observation series are given below:

RKZWT
CXWNZF
JLXBRVN
NHBDZVCR
VJSRBLTMW
HRKGWMDPTL
ZXWKDTNVSHQ
YPCQDKWZMTBJ

The observation series were made up in pairs of series, the same color name not occurring in both series, and in the tests the two members of a pair were given in succession, in order to avoid confusion between successive series.

The "observation tests" were especially satisfactory as tests and may be used successfully where immediate memory tests are required. Neither test, however, showed any deterioration in immediate memory due to asphyxiation.

a.		b.	
white	63	ecru	81
russet	84	black	52
gray	47	green	24
amber	28	lilac	73
violet	96	orange	35
red	58	blue	74
tan	14	buff	29
gold	85	rose	95
azure	46	drab	62
yellow	69	purple	79
scarlet	57	crimson	13
straw	25	slate	68
brown	18	pink	37
lavender	36	indigo	92

For visual memory the position memory board (fig. B) was used. This board has mounted in a vertical plane 49 miniature lamps arranged in a square pattern, the individual lamps 3 inches apart, vertically and horizontally. By means of a plug board and master key behind the board any number of lights from 1 to 14 can be lighted simultaneously in any chosen position. In practice the reactor was shown from three to seven lights for three seconds, and then required to chart the positions on a printed form (fig. 14). The lights were presented before or during the rebreathing test, and the charting was done immediately, or after a short or long interval. While no effects of asphyxiation were demonstrable up to the time at which the marking of the chart became impossible on account of disturbance of motor control, the method appears valuable for other than the rating work.

7. *Mathematical tests.*—Several mathematical tests were employed, the most satisfactory being the attention test. In this test two sheets, each containing 16 lines of 45 digits each, were used. Each of the 32 lines of digits was carefully made up so that the lines two sheets, each containing 16 lines of 45 digits each, were used. Each of the 32 lines of digits was carefully made up so that the lines presented equal difficulty. Before commencing the test a standard number of 12, 13, 14, or 15 was written before each line and the reactor required to add the digits in each line, beginning at the left, until the progressing sum equaled the standard number or one over that number, drawing in each case a line between the last digit of the group added and the next digit and writing the difference, if any, between the sum of the group and the standard number over the group. By changing the order of the standard number, 128 lines are available. A typical sheet of this test is shown in figure 15.

This test showed no definite asphyxiation effects prior to the period of general psychomotor decline, and is affected somewhat by eye conditions and practice effects. It has shown possibilities of advantageous use for other practical purposes, however, and work will be continued with it.

8. *Auditory tests.*—Tests on the sensitivity and acuity of the various sense organs. By using brief tests which permit the attainment of "attention peaks," it is demonstrable that the efficiency of the various sensory mechanisms does not show appreciable deterioration until the general psychophysical breakdown. Our detailed work has been principally on auditory efficiency, with some work on visual efficiency done before the ophthalmological section was organized.

Tests on the range of auditory perception of 12 reactors, with a set of 22 steel cylinders, with range up to 32,000 vibrations (fig. 16), showed no difference between normal and rebreathing series up to the point of general psychomotor inefficiency. Tests with the

acumeter (fig. 17) for sensitivity to the note of 256 vibrations are at present being carried on, and so far indicate no consistent deterioration of sensitivity until the late stages of asphyxiation. In other words, the reactor can hear as faint a sound, up to a late stage of asphyxiation, as he can in normal condition if his attention is good at the moment of listening. As has been previously explained, the "attention peaks" can be evoked even in relatively late stages of asphyxiation if the experiment is conducted by the methods usually employed by trained psychologists.

9. *Continuous reaction.*—The continuous-reaction board (fig. 18) which was used in one of our early tests, and which was, as a matter of fact, the starting point from which our final apparatus for the rating tests (LVN apparatus) was developed, could not be used for rating work because of the rapid but variable improvement with practice in its manipulation. In this apparatus 24 miniature lights are arranged in a circle, with a two-way switch at the base of each. By a master switch, a lamp is lighted; the reactor is required to turn off each lamp as soon as it lights by moving the appropriate switch; the turning off of one lamp turns on another at some point in the semicircle determined by the previously arranged interconnection of a switchboard concealed within the apparatus so that the reaction is a continuous one until the twenty-fourth lamp has been turned out, or may be continued through a longer period.

IV. FURTHER PSYCHOLOGICAL INVESTIGATIONS OF PROBLEMS OF AVIATION.

1. *Decrease of after-nystagmus times with successive rotations.*—The importance assigned, in the examination of aviators, to certain ocular movements which follow upon rotatory movements of the head and body has suggested an experimental investigation into the effect upon these ocular movements of rotations continued for several days or weeks together. Experiments have made it apparent that under certain circumstances persistent rotation in the clinical revolving chair leads to a considerable reduction in the violence and the duration of these characteristic ocular movements. In one case the duration of the after-nystagmus, e. g., as observed during May, 1918, fell from about 25 seconds to 11 seconds after several daily series lasting for a few minutes a day at a constant rate of one revolution in 2 seconds.

Further to investigate the effect of repetition upon ocular movements, six enlisted men were turned ten times a day (five times right and five times left) between June 6 and July 13, 1918. Two of the men were begun later than the others and intervals of one or more days interrupted here and there the continuity of the diurnal trials. The results are given in the accompanying Table I (fig. 19) and chart.

TABLE I.

		Brown.		Caplan.		Rahill.		Stewart.		Wichmann.		Ackermann.	
		Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.
June 6	R.	26.6	1.9	23.2	2.6	22.2	2.2	24.3	6.7				
	L.	27.6	1.7	29.4	2.5	20.6	1.5	25.6	1.5				
	1-5.	27.2	2.2	27.6	3.9	22.8	2.2	22.0	4.0				
	6-10.	27.0	1.6	25.0	2.8	20.0	.8	28.0	3.0				
7	R.												
	L.												
	1-5.												
	6-10.												
8	R.	22.3	2.9			20.8	1.4	22.0	2.6				
	L.	25.0	2.0			20.2	3.4	23.6	3.1				
	1-5.	24.0	4.0			21.6	2.3	19.7	.9				
	6-10.	16.7	4.3			19.4	2.7	26.0	1.3				
9	R.												
	L.												
	1-5.												
	6-10.												
10	R.	20.2	.6	19.6	1.9	20.2	3.4						
	L.	21.4	1.3	23.0	1.2	19.0	3.6						
	1-5.	21.0	1.6	22.2	2.0	20.6	2.9						
	6-10.	20.6	.5	20.2	2.2	18.6	3.4						
11	R.			14.5	1.3	15.0	2.4	17.6	2.1				
	L.			20.0	1.3	13.4	3.0	17.0	2.4				
	1-5.			17.5	2.5	17.0	2.8	19.2	1.4				
	6-10.			16.5	2.5	11.2	1.4	15.4	1.7				
12	R.	22.0	2.8	17.0	2.0	15.8	1.4	16.4	1.9	28.0	5.2		
	L.	22.8	2.2	20.7	1.8	13.8	2.2	16.0	1.6	28.0	4.0		
	1-5.	21.4	2.9	18.3	2.8	16.0	1.2	17.0	1.8	32.2	5.6		
	6-10.	23.4	1.9	17.5	2.3	13.6	2.1	15.4	1.5	23.8	2.6		
13	R.					12.8	1.7	14.0	4.0	28.6	2.1		
	L.					11.4	2.3	14.4	1.5	29.4	4.7		
	1-5.					13.6	1.9	16.6	2.1	31.8	2.2		
	6-10.					10.6	1.7	11.8	1.8	26.2	3.0		
14	R.	18.0	1.6	14.2	.6	12.4	1.5	9.6	1.7	23.4	2.0		
	L.	16.8	1.4	19.2	1.8	11.0	1.2	9.2	1.7	24.6	1.3		
	1-5.	18.6	1.1	17.0	2.8	13.2	.7	10.8	.6	25.4	.7		
	6-10.	16.2	1.4	16.4	2.5	10.2	.6	8.0	.8	22.6	1.3		
15	R.			14.2	2.6	10.8	1.0	6.8	1.0				
	L.			15.0	2.0	10.6	1.5	7.8	.9				
	1-5.			15.2	3.0	11.6	1.3	6.6	.9				
	6-10.			14.0	1.6	9.8	.6	8.0	.8				
16	R.												
	L.												
	1-5.												
	6-10.												
17	R.	24.4	2.7	13.0	3.0			8.8	1.8	27.6	2.7		
	L.	21.8	3.4	18.0	1.0			9.8	1.5	29.0	1.6		
	1-5.	22.6	2.5	16.0	.0			10.8	1.0	27.4	2.1		
	6-10.	23.6	4.5	15.0	5.0			7.8	1.4	29.2	2.2		
18	R.			14.4	1.5	14.2	2.6	10.8	2.1	23.2	2.2		
	L.			16.2	1.6	12.8	2.4	10.0	2.0	22.8	1.8		
	1-5.			15.6	1.1	14.0	2.8	12.0	2.0	24.6	2.1		
	6-10.			15.0	2.0	13.0	2.4	8.8	.7	21.4	.7		
19	R.	18.4	2.1	14.8	2.6	14.8	2.2	7.6	.5	23.6	1.9		
	L.	16.2	1.4	15.2	1.4	13.4	.9	7.8	1.4	23.6	2.5		
	1-5.	18.0	1.9	16.4	1.7	15.2	1.8	8.2	.6	23.6	2.5		
	6-10.	16.0	1.2	13.6	2.5	13.0	.4	7.2	.6	23.6	1.9		
20	R.			11.4	1.1	13.4	1.8	5.6	1.5	19.0	2.0		
	L.			11.4	.9	11.0	2.0	5.0	1.2	22.2	1.4		
	1-5.			12.0	.8	14.0	1.6	6.6	.9	21.6	1.3		
	6-10.			10.8	.6	10.4	1.3	4.0	.0	19.6	2.5		
21	R.	15.2	1.0	9.4	.7	7.2	.6	1.6	1.9	15.8	1.4		
	L.	13.4	.5	11.2	1.0	7.8	.6	1.0	1.6	17.2	2.6		
	1-5.	14.6	1.3	10.2	1.0	7.6	.9	2.6	1.0	17.0	2.4		
	6-10.	14.0	.8	10.4	1.3	7.4	.5	.0	.0	16.0	2.4		

TABLE I—Continued.

		Brown.		Caplan.		Rahill.		Stewart.		Wichmann.		Ackermann.	
		Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.
June 22	R.	......	......	10.0	.8	......	......	5.4	.9	17.0	2.4	......	......
	L.	......	......	10.8	1.7	......	......	2.2	1.7	18.8	2.2	......	......
	1–5.	......	......	10.2	.7	......	......	4.8	1.4	18.8	1.9	......	......
	6–10.	......	......	10.6	1.8	......	......	2.8	1.1	17.0	2.4	......	......
23	R.	......	......	......	......	......	......	......	......	......	......	......	......
	L.	......	......	......	......	......	......	......	......	......	......	......	......
	1–5.	......	......	......	......	......	......	......	......	......	......	......	......
	6–10.	......	......	......	......	......	......	......	......	......	......	......	......
24	R.	11.6	1.5	7.0	1.2	7.6	2.1	1.4	1.4	15.0	2.0	......	......
	L.	11.2	1.0	8.4	1.5	7.2	1.8	.6	.9	16.0	2.4	......	......
	1–5.	11.8	1.0	8.0	.8	8.6	1.4	1.2	.8	16.4	1.3	......	......
	6–10.	11.0	1.2	7.4	2.4	6.2	1.8	.8	.5	14.6	2.3	......	......
25	R.	......	......	7.8	1.0	7.6	2.3	.0	.0	12.8	2.2	......	......
	L.	......	......	8.2	1.0	6.6	1.7	.0	.0	14.2	1.8	......	......
	1–5.	......	......	8.4	1.1	2.3	1.5	.0	.0	15.4	1.9	......	......
	6–10.	......	......	7.8	1.2	1.7	1.7	.0	.0	11.6	1.3	......	......
26	R.	10.8	1.4	6.6	1.3	8.6	.5	.0	.0	10.4	1.7	......	......
	L.	9.4	.5	8.6	2.5	6.8	1.0	.0	.0	10.8	1.4	......	......
	1–5.	10.8	1.4	8.2	2.2	7.4	1.1	.0	.0	11.4	1.5	......	......
	6–10.	9.4	.7	7.0	2.0	8.0	.8	.0	.0	9.8	2.2	......	......
27	R.	......	......	......	......	......	......	......	......	......	......	29.4	2.3
	L.	......	......	......	......	......	......	......	......	......	......	31.2	2.6
	1–5.	......	......	......	......	......	......	......	......	......	......	31.4	2.3
	6–10.	......	......	......	......	......	......	......	......	......	......	29.2	3.0
28	R.	......	......	......	......	......	......	......	......	......	......	28.4	1.3
	L.	......	......	......	......	......	......	......	......	......	......	29.8	1.0
	1–5.	......	......	......	......	......	......	......	......	......	......	25.2	1.8
	6–10.	......	......	......	......	......	......	......	......	......	......	26.0	2.4
29	R.	......	......	......	......	......	......	......	......	......	......	21.6	1.1
	L.	......	......	......	......	......	......	......	......	......	......	22.6	2.1
	1–5.	......	......	......	......	......	......	......	......	......	......	20.6	3.3
	6–10.	......	......	......	......	......	......	......	......	......	......	16.6	1.9
30	R.	......	......	......	......	......	......	......	......	......	......	......	......
	L.	......	......	......	......	......	......	......	......	......	......	......	......
	1–5.	......	......	......	......	......	......	......	......	......	......	......	......
	6–10.	......	......	......	......	......	......	......	......	......	......	......	......
July 1	R.	14.8	1.8	......	......	10.4	1.9	......	......	20.8	1.4	18.2	2.6
	L.	14.4	1.7	......	......	7.4	2.5	......	......	23.4	2.9	19.0	3.2
	1–5.	13.0	1.2	......	......	7.6	2.5	......	......	24.0	2.4	20.6	3.3
	6–10.	16.2	1.0	......	......	10.2	1.4	......	......	20.2	1.0	16.6	1.9
2	R.	15.4	.5	......	......	6.0	1.6	......	......	17.8	3.6	14.2	1.9
	L.	14.8	.7	......	......	6.0	.8	......	......	18.4	1.1	16.8	1.4
	1–5.	15.2	.3	......	......	6.8	1.0	......	......	17.4	2.1	16.4	2.7
	6–10.	15.0	.1	......	......	5.2	1.4	......	......	18.0	2.2	14.6	1.3
3	R.	13.4	1.5	......	......	......	......	......	......	14.2	3.4	15.8	1.8
	L.	13.8	1.1	......	......	......	......	......	......	13.6	1.9	15.2	1.2
	1–5.	14.2	1.0	......	......	......	......	......	......	14.2	3.8	16.2	1.4
	6–10.	13.0	1.6	......	......	......	......	......	......	13.6	1.5	14.8	1.4
4	R.	......	......	......	......	......	......	......	......	......	......	......	......
	L.	......	......	......	......	......	......	......	......	......	......	......	......
	1–5.	......	......	......	......	......	......	......	......	......	......	......	......
	6–10.	......	......	......	......	......	......	......	......	......	......	......	......
5	R.	......	......	......	......	8.4	1.3	......	......	17.4	2.3	13.2	1.4
	L.	......	......	......	......	6.8	1.0	......	......	15.2	2.2	14.4	.9
	1–5.	......	......	......	......	8.8	1.0	......	......	15.4	2.5	13.8	1.0
	6–10.	......	......	......	......	6.4	.9	......	......	17.2	2.2	13.8	1.4
6	R.	......	......	......	......	8.4	.7	......	......	13.0	1.6	12.0	1.2
	L.	......	......	......	......	6.2	1.0	......	......	14.2	.3	14.6	.5
	1–5.	......	......	......	......	8.2	.6	......	......	14.0	1.2	13.0	1.2
	6–10.	......	......	......	......	6.4	1.3	......	......	13.2	1.0	13.6	1.4
7	R.	......	......	......	......	......	......	......	......	......	......	......	......
	L.	......	......	......	......	......	......	......	......	......	......	......	......
	1–5.	......	......	......	......	......	......	......	......	......	......	......	......
	6–10.	......	......	......	......	......	......	......	......	......	......	......	......

TABLE I—Continued.

		Brown.		Caplan.		Rahill.		Stewart.		Wichmann.		Ackermann.	
		Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.	Av.	M.V.
July 8	R.	18.0	2.0			12.6	1.3			18.4	2.1	12.2	2.2
	L.	16.4	1.9			10.6	1.9			17.0	.4	12.2	1.0
	1–5.	15.8	1.8			13.4	.5			17.4	1.8	12.2	2.2
	6–10.	18.6	1.5			9 8	1.0			18.0	4.0	12.2	1.0
9	R.	13.4	1.9			10.6	1.3			11.8	1.8	10.8	1.4
	L.	11.6	1.9			9 4	.9			10.6	1.4	12.4	1.1
	1–5.	14.6	.9			10.2	1.1			12.0	1.6	12.6	.9
	6–10.	10.4	.9			8.8	.6			10.6	1.5	10.6	1.3
9	R.											8.2	1.0
	L.											8.2	1.0
	1–5.											8.8	1.0
	6–10.											7.6	.7
10	R.									9.2	1.8	11.0	.4
	L.									9.8	2.6	9.8	1.0
	1–5.									8.4	1.7	10.0	.8
	6–10.									10.6	2.3	10.8	1.0
11	R.					9.6	.9					9.6	1.3
	L.					9.0	.4					8.4	1.1
	1–5.					10.0	.4					9.6	.9
	6–10.					8.6	.5					8.4	1.3
12	R.					8.6	.8					9.2	.5
	L.					8.2	.3					9.0	.4
	1–5.					8.8	.6					9.4	.4
	6–10.					8.0	.4					8.8	.6
13	R.					7.2	.3					7.6	1.5
	L.					6.8	.6					6.8	.6
	1–5.					7.2	.6					7.8	1.3
	6–10.					6.8	.3					6.6	.9
14	R.												
	L.												
	1–5.												
	6–10.												
15	R.											6.4	.5
	L.											6.6	.7
	1–5.											6.6	.7
	6–10.											6.4	.5
16	R.												
	L.												
	1–5.												
	6–10.												
17	R.											7.6	.5
	L.											7.2	.3
	1–5.											7.6	.5
	6–10.											7.2	.3
18	R.												
	L.												
	1–5.												
	6–10.												

The method of observation and record[1] was improved (1) by timing the rotatory movement of the chair with the sound of a seconds' met-

[1] In adopting a definite standard technique for the conduct of a large number of examinations to be held at scattered stations by many examiners under varying conditions, the use of complicated instruments of precision is, of course, neither necessary nor practicable. Intervals of a day or more between turnings were sometimes inevitable owing to the military duties of the men examined. It will be noted that there occurs quite a variation in the readings from day to day. This may be due to slight variation in the stimulation employed or to inaccuracies in reading the nystagmus. The former factor was overcome as far as possible by timing the rate of turning with a stopwatch, while the latter was minimized by having all the readings taken by one observer. These variations, however, do not vitiate the main results as stated above.

ronome used to replace a stop watch and (2) by recording the later phases of nystagmus upon a revolving drum with time marker, Jacquet seconds clock, and telegrapher's key. The auditory-kinaesthetic rhythm incited by the metronome forms a much more natural and accurate control for the rotation of the chair than the stop watch, and the graphic record of eye movements eliminates the double error of anticipating and delaying the cessation of nystagmus, an error inherent in the single movement of the thumb or finger upon the stem of the watch. This double error may amount to several seconds. The usual stop-watch method offers no means of control over the variable errors of expectation and habituation and the constant errors of time. All of these errors are, of course, scrupulously calculated in any recognized method of science.

These experiments were conducted by assistants in the laboratory. From time to time the method was inspected, and occasional readings were made of after-nystagmus with the stop watch. In the table each average time for 5 right turns and 5 left turns is given, as well as the average of the first 5 and the last 5 turns in each series. Mean variations are calculated in each case. In every instance the rate was 10 turns in 20 seconds. Intervals of two minutes (between right and left) and three minutes (between pairs) were observed. In a few cases the regular series was interrupted or shortened by severe organic disturbances revealed by nausea, qualmishness, pallor, excessive respiration, and general distress.

The results bear evidence of the decline of the duration of after-nystagmus (1) from day to day and (2) from trial to trial within a single period of experimentation.

The average times for the four observers who began on June 6 run as follows from day to day:

	Seconds.		Seconds.
June 6	24.9	June 18	13.0
8	22.3	19	13.5
10	20.6	20	9.6
11	16.2	21	8.3
12	18.0	22	7.1
13	13.6	24	6.8
14	13.8	25	5.0
15	10.8	26	6.3
17	15.9		

In 20 days, then, the decrease in time exceeds 18 seconds (24.9—6.3 seconds). The drop in time is fairly consistent in spite of the fact that it proved to be impossible to arrange, without exception, the daily program. The temporal decline is graphically expressed in the chart, which is based upon the nystagmus for the first, fifth, tenth, and fifteenth turning days, regardless of calendar dates, for all six

subjects. The initial times for all subjects fell within 22–31 seconds; and they decline at somewhat unequal intervals for the different men. The total range of decline expressed in whole numbers for the first 10 days stood as follows:

Subject A	30—12=18 seconds	Subject R	21—14= 7 seconds
Subject B	27—10=17 seconds	Subject S	25— 8=17 seconds
Subject C	26—11=15 seconds	Subject W	28—15=13 seconds

The difference is not very great, save in the case of R, whose times were least shortened within this limited time. R dropped sharply (14 to 8 seconds), however, within the next five days, while S fell off to zero.

To revert to the decrease in time of the ocular movements during the period of experimentation each day, the times nearly always decline during the 10 trials, as in the case of the May experiments made upon the single subject. The few negative cases are significant. The most striking case appears in S's first two days. On these two days the subject became so violently nauseated that the trials had to be broken off after the sixth turn. Thereafter the ocular movements grew, from day to day, much less violent and of smaller excursion, qualmishness disappeared, and the nystagmus rapidly lessened in duration. All of the other negative cases of more than a second or so occurred just after two or more blank days and they fell in with an absolute increase in nystagmus time, and usually with a greater violence in the general organic effects of rotation. These blank days were coincident with holiday leaves for the subjects during which their daily routine was interrupted. The disturbance of routine may very well have led to a physiological disturbance producing a cumulative effect and masking the usual decline during the last half of the period.

It seemed altogether probable that the change of after-nystagmus, which occurred not only from turn to turn, but also from day to day, should be a function of elapsed time as well as of repetition. The accompanying table (II) gives the relative frequency of increase and decrease in after-nystagmus after intervals and immediately after turning days. The totals for all subjects suggest that the blank days retard the gradual decline to which attention has been called. But a scrutiny of the table will make it apparent that virtually all the positive evidence is confined to the figures for the last two subjects (R. and W.), who also reported an increased violence in the apparent visual movements and in organic disturbances after intervals of rest.

TABLE II.

	After interval.		After no interval.	
	Increases.	Decreases.	Increases.	Decreases.
Ackerman	1	5	3	16
Brown	8	12	2	4
Caplan	1	7	7	13
Stewart	2	6	4	16
Rahill	9	5	6	24
Wichmann	8	2	6	22
Total	29	37	28	95

It is impossible, then, to generalize upon the effect of time interval. Repetition of turning certainly leads, under certain circumstances, to a decrease in after-nystagmus. But that the decline depends in any fixed way upon the length of the temporal interval can not be maintained upon the basis of the evidence at hand. The decline is not to be laid to a simple process of adaptation in the receptor organs of the labyrinth, for such sensory adaptations as are best known—visual, tactual, and thermal—are of brief duration, and, furthermore, they rapidly disappear with the lapse of stimulation. Still less is the effect of repetition to be disposed of as a case of "fatigue," a term which the uncritical lay reader might readily suggest. Nothing like fatigue (used in the sense of waste products and lowered metabolism) is here observed; and the proposal of that term as an hypothesis would be a loose use of the argument from analogy, which explains nothing. If genuine fatigue were actually induced by rotation, its effects would scarcely remain unmodified for four or five days. The explanation of the observed decline in nystagmus remains, therefore, for further experimentation made under more favorable technical conditions than the department has been able to command.[1]

The present experiments have demonstrated (1) that organic disturbances tend to disappear under rotation day after day and (2) that the after-nystagmus is reduced in violence and in duration under repetition (*a*) within a single experimental series—a total rotation of about three minutes—and (*b*) day by day. In 10 turning days, with 10 observations made each day, the average decline for six subjects was approximately 15 seconds, or more than half the original duration finally. The experiments have illustrated (3) the fact that

[1] Unquestionable evidence now available (see editorial insert immediately following) disproves the statement that "repetition of turning certainly leads to a decrease in after-nystagmus." Of the six individuals used by the psychologic department for these experiments not one was examined physically beforehand; two of these six were discovered subsequently to be pathologic, the other four had meantime been lost sight of. This failure to establish positively the normality of the individual subjects before proceeding with the series of tests is most unfortunate as it makes it impossible to draw any scientific conclusions from the data obtained.

casual observation of nystagmus involves a number of observational errors which may be eliminated by the standardized procedures of the psychological laboratory.

EDITORIAL INSERT.

The foregoing sets forth the result of certain ear investigations which were undertaken in the department of psychology. Neither the findings in the individual cases herein reported nor the deductions drawn from the series are in accord with the findings and deductions of the otologic department.

Several thousand reexaminations of fliers, made by skilled otologists who have been occupied with daily turning chair examinations of the internal ear for unbroken periods covering 12 to 18 months, do not indicate reduction in the duration of nystagmus following rotation. A carefully analyzed report of 541 consecutive cases examined by a single observer on three of the southern flying fields follows:

One hundred and fifty-six men examined. Flying period, 0 to 25 hours. Average nystagmus—turning to right, 25 $\frac{40}{156}$, turning to left, 25 $\frac{35}{156}$ seconds.

One hundred and sixty-nine men examined. Flying period, 25½ to 50 hours. Average nystagmus—turning to right. 25 $\frac{85}{169}$; turning to left, 25 $\frac{40}{169}$ seconds.

Fifty-nine men examined. Flying period, 50½ to 75 hours. Average nystagmus—turning to right, 19 $\frac{1}{59}$; turning to left, 18 $\frac{37}{59}$ seconds.

Thirty-seven men examined. Flying period, 75½ to 100 hours. Average nystagmus—turning to right, 24 $\frac{19}{37}$; turning to left, 25 $\frac{4}{37}$ seconds.

Twenty-one men examined. Flying period, 100½ to 150 hours. Average nystagmus—turning to right, 25 $\frac{18}{21}$; turning to left, 25 $\frac{8}{21}$ seconds.

Thirty-four men examined. Flying period, 150½ to 200 hours. Average nystagmus—turning to right, 26 $\frac{4}{34}$; turning to left, 25 $\frac{8}{34}$ seconds.

Thirty-two men examined. Flying period, 200½ to 250 hours. Average nystagmus—turning to right, 23 $\frac{5}{32}$; turning to left, 23 $\frac{13}{32}$ seconds.

Fourteen men examined. Flying period, 250½ to 300 hours. Average nystagmus—turning to right, 23 $\frac{2}{14}$; turning to left, 25 $\frac{6}{14}$ seconds.

Nineteen men examined. Flying period, 300½ to 1,000 hours. Average nystagmus—turning to right, 26 $\frac{4}{19}$; turning to left, 25 $\frac{11}{19}$ seconds.

The average nystagmus of accepted applicants among 75,000 examinations showed on turning to the right, 23 seconds, and on turning to the left, 23.1 seconds. It will be noted that the average nystagmus of the above series is somewhat higher. It will also be shown by the fact that without dividing these cases by the hours of flying, the average on turning to the right, was 24.6 seconds, and turning to the left, 24.4 seconds.

A series of daily observations made by otologists who have had years of daily practice in the application of turning chair tests of the internal ear was conducted in the laboratory at Mineola. The subjects of this series of tests were 10 adult individuals carefully determined by previous physical examination to be normal. (No evidence exists as to the normality of four subjects of the tests conducted by the psychologic department; the other two, A and S, were

found upon physical examination to be pathologic. It must be especially emphasized that pathologic conditions of the internal ear not affecting hearing may be of a nature very difficult to detect by ordinary observations; for example, the sequelæ of mumps, lues, typhoid fever, and other acute infectious diseases.) Six subjects were turned each morning (10 turns to the right in 20 seconds and 10 turns to the left in 20 seconds) and four subjects were turned in the same manner both morning and evening. It was noted as the subjects became accustomed to the vertigo induced by turning that with the proficiency attained in executing voluntary motor coordinations manifest in pointing tests and fall tests, a commensurate proficiency became apparent in voluntary fixation of the gaze through daily practice. This acquisition of an increased fixation control of the voluntary eye movements resulted in a lessening of the duration of the resulting nystagmus in some cases. That this was in no sense the result of change in character or intensity of the vestibular stimulus was proven by placing before each subject's eyes a pair of plus 20 lenses which rendered fixation of the gaze impossible. Observations of the resulting nystagmus, made not only through these lenses but behind them, confirmed beyond qeustion the finding that there was no reduction in the duration of the nystagmus following nine weeks of uninterrupted tests.

FREY, J. C.

Date.	A. M.		P. M.		Date.	A. M.		P. M.	
	Right.	Left.	Right.	Left.		Right.	Left.	Right.	Left.
Sept. 26	23	22	21	20	Oct. 26	20	....	20	....
27	20	22	24	28	28	21	22	21	20
28	23	....	17	....	29	19	17	18	16
30	21	20	19	18	30	20	19	21	18
Oct. 1	19	19	17	18	31	25	22	19	19
2	20	18	18	18	Nov. 1	21	17	18	16
3	19	21	18	19	3	19	....	20	....
4	20	21	21	19	4	20	19	19	18
5	19	....	18	....	5	22	19	19	18
7	20	21	20	18	6	22	....	20	....
8	23	17	19	17	7	24	....	21	....
9	17	21	19	20	8	21	21	20	22
11	18	19	21	17	11	21	26	18	20
12	21	....	19	....	12	27	26	25	20
14	21	19	20	19	13	21	....	19	....
15	20	22	18	23	14	19	....	19	....
16	19	19	19	19	16	21	....	20	....
17	22	20	21	18	18	20	....	21	....
18	24	18	19	16	19	21	....	20	....
21	19	20	19	18	20	22	25	19	20
22	21	18	19	21	21	19	....	19	....
23	21	20	19	21	22	24	21	20	20
24	22	18	17	17	25	23	....	20	....
25	23	....	19	....	26	20	....	19	....

SCHNEIDER, T. G.

Date.	A. M. Right.	A. M. Left.	P. M. Right.	P. M. Left.	Date.	A. M. Right.	A. M. Left.	P. M. Right.	P. M. Left.
Sept. 28	25	....	20	....	Oct. 8	20	16	18	16
30	26	25	23	22	9	19	20	21	20
31	26	....	25	....	10	21	25	24	16
Oct. 1	29	....	21	....	12	22	....	19	....
2	28	28	19	24	14	19	17	18	19
4	19	25	18	21	15	21	22	18	21
5	18	....	20	....	16	22	25	19	15
7	23	26	16	17	17	28	26	25	21

SCHNEIDER, T. G.—Continued.

Date.	A. M.		P. M.		Date.	A. M.		P. M.	
	Right.	Left.	Right.	Left.		Right.	Left.	Right.	Left.
Oct. 18	23	18	23	19	Nov. 7	26	....	21	....
19	19	....	24	....	8	27	26	22	24
21	19	18	16	19	9	25	....	27	....
23	17	20	18	18	12	26	....	22	....
24	24	24	19	18	13	26	27	22	28
25	20	20	17	18	14	28	26	24	24
26	27	....	21	....	15	25	....	24	....
28	27	24	24	23	16	30	....	27	....
29	22	24	21	29	18	28	....	24	....
30	26	23	28	29	19	24	25	26	21
31	29	27	27	24	20	27	23	23	20
Nov. 1	21	17	21	....	21	25	29	25	21
4	29	28	26	26	22	30	....	25	....
5	31	27	27	24	25	25	....	20	....
6	21	29	28	30	26	27	....	24	....

ENNIS, L. E.

Sept. 26	26	26	20	19	Oct. 19	18	....	18	....
27	30	24	28	18	20	18	20	20	20
28	30	....	26	....	22	25	26	26	27
30	31	25	28	25	23	20	16	19	20
Oct. 2	24	24	22	30	24	22	20	21	20
3	27	24	31	26	25	17	18	15	20
4	....	23	....	20	26	28	....	25	....
5	22	....	16	....	28	19	21	25	23
7	20	....	23	....	29	23	30	25	27
10	25	21	26	19	30	26	21	23	25
11	24	22	19	19	31	20	24	24	20
12	23	....	21	....	Nov. 3	21	....	22	....
14	24	21	19	21	4	28	....	24	....
15	20	21	21	19	5	18	24	20	23
16	20	20	19	16	8	28	28	29	23
17	24	29	23	23	9	26	....	28	....
18	22	17	19	16					

LONG, C. M.

Sept. 26	26	24	26	26	Oct. 25	15	....	16	....
27	25	24	27	20	28	19	16	18	18
28	24	....	22	....	29	19	19	18	20
30	23	27	21	22	30	21	20	20	20
Oct. 1	25	....	23	....	31	24	23	24	23
2	26	23	24	20	Nov. 1	18	23	17	24
3	25	25	21	20	3	23	....	24	....
4	19	16	20	16	4	27	....	26	....
7	17	14	19	20	5	18	20	18	18
8	18	....	18	....	6	21	20	20	18
9	18	....	18	....	7	18	....	18	....
10	16	16	18	16	12	22	21	20	19
11	17	18	17	16	13	21	20	23	20
12	20	....	18	....	14	24	....	21	....
14	18	17	17	16	16	25	....	25	....
15	19	....	18	....	18	22	21	21	22
17	20	19	19	16	19	25	23	24	22
18	20	22	19	18	20	19	24	18	21
19	22	....	21	....	21	26	....	24	....
21	21	17	19	16	22	23	20	30	19
22	21	25	18	19	23	18	....	18	....
23	16	18	17	16	25	23	....	20	....
24	14	22	19	17	26	20	....	18	....

TRIMMER, H. M.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 26	24	28	Oct. 24	21	24
27	20	28	25	21	23
28	26	25	28	22	23
30	25	27	29	25	27
Oct. 1	27	22	30	25	25
2	22	25	31	28	26
3	21	20	Nov. 1	19	23
4	18	21	3	20	22
5	21	21	4	27	26
7	20	23	5	24	23
9	20	22	6	25	23
10	24	23	7	20	19
11	18	21	8	29	28
12	24	20	9	22	24
14	18	24	11	24	30
15	20	22	12	24	24
16	19	22	13	25	21
17	24	27	16	26	24
18	25	21	18	26	28
19	24	24	19	22	26
21	20	18	21	24	23
22	21	22	22	22	21
23	22	28	26	25	21

McCABE, C. J.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 28	27	27	Oct. 28	22	25
Oct. 1	33	25	29	25	28
2	27	27	30	23	22
3	22	23	Nov. 1	26	29
4	20	19	3	26	25
5	23	20	5	30	30
7	20	21	6	27	29
8	23	21	7	23	21
9	24	24	8	21	19
10	22	22	9	27	26
11	24	23	11	25	22
12	23	20	12	24	21
14	23	22	13	27	25
15	21	19	14	26	28
16	22	24	16	24	23
17	22	23	18	25	22
18	24	19	19	26	22
21	23	23	21	25	24
22	19	24	22	21	24
23	18	21	23	25	23
24	17	19	26	24	21
26	25	24			

BROWNING, E. L.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 26	26	28	Oct. 25	20	91
27	22	26	26	30	28
28	24	25	28	26	24
30	27	23	29	18	19
Oct. 1	25	24	30	22	23
2	27	24	31	22	27
3	22	20	Nov. 5	27	26
4	22	21	8	27	26
5	21	20	9	25	22
7	23	19	11	30	30
8	21	20	12	25	27
9	22	23	13	20	23
10	25	21	14	26	28
11	16	20	16	25	26
12	20	21	18	23	24
14	23	21	19	21	22
15	20	16	20	24	25
22	24	19	21	30	30
23	22	21	22	26	27
24	16	19			

HAYMAN, G. C.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 28	40	37	Oct. 30	28	29
Oct. 2	38	36	31	30	20
3	24	30	Nov. 1	30	28
7	31	30	3	23	27
8	33	30	4	26	28
9	31	34	5	32	33
10	32	34	6	30	26
11	30	33	7	27	21
12	30	30	9	29	26
14	32	28	11	30	28
15	30	32	12	29	26
16	23	27	13	36	30
17	31	30	14	29	27
18	26	25	16	30	27
19	25	....	17	30	27
21	27	25	18	31	30
23	33	29	20	28	28
24	23	32	21	34	29
25	24	23	22	30	25
26	34	27	26	30	26
29	34	34			

BRAMLEY, R. H.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 28	30	33	Oct. 23	20	22
Oct. 1	29	33	25	19	23
2	40	31	26	25	31
3	25	29	28	21	23
7	29	29	29	26	28
8	24	29	30	28	26
9	25	26	31	24	28
10	29	29	Nov. 1	25	24
11	27	28	3	25	24
12	22	24	4	27	28
15	22	21	5	25	28
16	25	24	7	26	29
17	28	26	8	26	28
18	27	32	9	35	37
19	21	22	12	30	38
21	19	21	14	32	30
22	22	28			

JAFFA, B. B.

Date.	Right.	Left.	Date.	Right.	Left.
Sept. 28	26	34	Nov. 1	26	26
Oct. 2	28	31	3	27	27
3	34	30	4	26	25
11	31	31	5	30	29
12	28	29	6	25	27
14	22	26	7	31	30
15	26	30	9	31	28
16	30	33	11	36	28
18	27	30	12	30	28
19	25	25	13	32	34
21	25	24	14	29	30
22	30	30	16	25	27
23	20	21	18	27	26
24	23	21	19	28	27
25	20	23	20	28	26
26	24	23	21	31	32
28	24	25	22	31	29
30	28	27	26	30	26
31	22	25			

It is of supreme importance for the reader to note the cardinal difference between the series of 541 examinations of fliers here reported, in whom no reduction in the duration of nystagmus was encountered, and the turning chair tests conducted upon 10 subjects for 9 consecutive weeks. The flier *can not* practice the fixation of gaze owing to the variability of conditions under which he flies; the sub-

ject in the turning chair *must* fix his gaze accurately after each turning, thereby undergoing a very intensive practice in gaze fixation.

It follows, therefore, that *when a marked redutcion in duration of nystagmus is encountered it must be regarded as indicating a definite departure from the normal.* Examples in point are the following three cases:

M, flying instructor, reported that his cadet students were prone to level off with left wing down; officer in charge of flying and post commander observed that M always leveled off with the right wing down. He was ordered up for physical examination, which revealed pathologic condition of his internal ear, evidenced among other findings by 6 seconds' duration nystagmus after turning right.

W, a flier, who had been determined by a physical examination to be normal; after completion of flying training in England had several months' combat service on the western front, giving daily evidence of satisfactory flying ability. Officer in charge of flying noticed gradually increasing loss of flying ability; three weeks' rest was not followed by the expected improvement, and he was ordered up for a reexamination. His nystagmus record on entering flying training was 26 seconds after right turn, 26 seconds after left turn; on this reexamination it was found to be 7 seconds right turn, 9 seconds left turn. Further examination revealed luetic internal ear disease; the aviator then stated he had acquired syphilis since admission into the service.

Lieut. X under flying instruction, was reported by instructor as a very dangerous pupil, having repeatedly leveled off with left wing down; instructor refused to take further risks. Officer in charge of flying upon looking up record of physical examination found that through clerical error this man had been reported fit for flying training instead of unfit for flying training owing to subnormal nystagmus following turning. In all three of these cases the diagnosis of internal ear abnormality was made by the flying instructor solely upon the evidence furnished by the *flier's* performance in the plane. Further evidence of this character was discovered in certain of the flying fields following epidemics of mumps, a condition affecting the internal ear with especial frequency. [End of editorial insert.]

2. *Orientation.*—Methods have been devised for determining the promptness and the accuracy with which the aviator gets his bearings, finds his way, and remembers his course in the air. The ability to keep directions and to maintain a correct orientation on the ground or in flight differs widely from individual to individual, and since both personal safety and successful execution depend upon clear and prompt orientation, the test of a pilot's ability in this regard is of great importance. Various typical means of orientation distinguish one flier from another. The main "types" discovered and described

include (1) the compass type, or those individuals who get their bearings by the cardinal directions; (2) the mapping type, individuals who refer places and directions to an imaginary map upon which north is always before and east at the right of the observer; (3) the pointing type, which depends upon kinæsthetic factors for orientation; (4) the pathfinding type, which relies upon the recognition of landmarks; (5) the fragmentary type, which is oriented only in certain regions and under certain circumstances; (6) the disoriented type, which includes the habitually confused and muddled; and (7) the lost type of individual, who takes little or no account of spatial clues to position and direction and who can not be trusted to explore new regions or to search out a new objective. Both the accuracy of exploration and the appropriate method of instruction in map making and map reading and in reconnaissance depend upon the flyer's orientational type.

Apparatus (figs. 20 and 21) has been built in the laboratory for discovering whether the pilot or the observer is easily lost or disoriented, whether he knows and keeps his compass points, and whether he is capable of translating verbal orders to fly to a named objective into a plan of flight, or of charting a terrain from his aerial observations, or of retracing his course of flight by the observation of landmarks.

The test of the methods evolved has made it evident that it is possible to determine within a few minutes the "type" of the aviator with respect to orientation, and also his facility in getting his bearings and in maintaining his directions under the exigencies of flight.

3. *Association reaction times.*—A large amount of work has been done on the association reaction test using the chronoscope and voice keys (fig. 22). In this test a word, "stimulus word" spoken by the psychologist, starts the hand of the chronoscope in rotation, and a word, "response word" spoken by the reactor, stops the hand. The time between stimulus and reaction, the time required to "think of the reply" is then read directly on the dial in thousandths of a second. Stimulus words of a definite character are used (e. g. nouns), and a response word of definite rotation to the stimulation word (e. g., verb naming action which could be exerted by whatever is designated by the noun) is required. In this way a rating on the basis of the time required for the answer, and also on the reliance and specific appropriations of the answers is possible. These vary according to the general mental ability and the particular condition (fatigue, etc.) of the reactor. So far, the work has been largely directed to the development of standard lists of stimulus words (which in itself requires a large amount of research) and the perfecting of a rating scheme.

The foregoing enumeration by no means exhausts the immediate possibilities and needs of investigation of the points of general and special fitness and adaptability noted in an earlier summary (Chap. I). Nor does it include all the work on these topics which is under way in the psychological laboratory. It indicates, however, the scope of the work in the direction of classificatory tests, and together with the preceding statements will serve as a guide to psychologists in the various fields in observing fliers and flying conditions and collecting information useful for further development of practical aid to the service.

VII.—DEPARTMENT OF NEUROLOGY AND PSYCHIATRY.

The work of this department touches the aviation problems at three vital points: (1) By the detection in the aviator of symptoms of nervous and mental diseases; (2) by the recognition of latent trends of temperament which, if not recognized in time and treated rationally, increase the liability of the flier either to become inefficient or to lose morale and esprit de corps, and (3) finally by supplementing the information already obtained in other departments in regard to the aviator's potential flying capacity with additional data bearing upon his temperament and personality. This knowledge to be used in the selection of fliers for special tasks.

The examiner should keep constantly before his own mind the fact that the chief purpose of these personality studies is to determine the fitness of an aviator to withstand the nervous strain of flying at the front. For this reason, although clinical methods of examination are used in taking these histories, they should not be judged by ordinary clinical standards—as the purpose is not to carry the analysis of the aviator's personality further than is necessary to estimate his potential as a flier under war conditions.

The chief sources of information for data upon which judgment of the personality is based are (1) the Aviator under examination, (2) other Departments in the laboratory, (3) the Flight Commander, and (4) the Flight Surgeon. A spirit of sympathetic cooperation is necessary in gathering this data and neurologists and psychiatrists should remember they are attempting merely to supply some of the links in a relatively long chain of evidence.

In estimating the nervous capacity to withstand strain the examiner should give particular attention to the following points:

(1) What were the chief reasons influencing the aviator in choosing this branch of the service? Did the love of adventure, desire for independent action, or interest in machinery, or a combination of all these elements enter into the decision? Does he feel that he is making good and is he satisfied with his original decision? The

statements of experienced aviators show how much success in flying depends upon making that particular decision clean cut and then accepting it as final. Indecision, a sense of inadequacy, or idle regret at having chosen work for which he is not fitted temperamentally may lead to a chain of symptoms culminating in a psychosis or psychoneurosis.

(2) Impressions of the aviator's readiness or disinclination to face difficult situations fairly and squarely should be recorded. Evidence of a tendency to dodge critical events in life, a habit which if not corrected may become the starting point for morbid fears and obsessions, should be noted. An experienced and daring aviator may lose nerve suddenly as the result of not having definitely settled some relatively trivial event of a personal nature. States of irresolution and doubt as well as compulsions antagonistic to efficiency often develop out of buried mental complexes.

(3) The question should be asked whether the members of the immediate family approve or disapprove of his flying, making it easy or difficult for the aviator to devote his entire attention to his work.

(4) Notice should also be taken of the occurrence of nervous or mental disorders in the family history.

Associated with the effort to present brief records containing only the essential facts in each case, there should also be a clear appreciation of the number and variety of factors which may affect the behavior of the aviator. Each analysis should be based on the consideration of the active forces influencing behavior in critical situations. The restriction of the investigation merely to taking a cross section of life at any single level in the life curve is not sufficient. Remotely antecedent events in life, such as attacks of disease, accidents, circumstances giving rise to bad habits, or poor educational opportunities, may have a direct practical bearing on the performances of the aviator in a plane.

The following cases are cited to illustrate the advantages of a very brief summary of the life history.

CASE 1.—Personality rating, "A." No indication that he will require any special attention nor be predisposed to collapse under strain.

——— ———, 1st lieut., A. S. S. C.

Aviation history: No "repeats" in ground school. Licensed pilot. 80 hrs. flying to date. No accidents.

Personal history: No serious illness nor accidents. Public-school education; not college graduate. Has worked hard for living and enjoyed it. No grouches. Normally optimistic. Advised by his captain in Infantry to transfer to aviation. Glad he did so; enjoys flying; feels he is making good.

Physical examination: Height, 5 ft. 6 in.; weight, 132; age, 23. Nothing abnormal.

Tests (low tension): Very good, "A."

Personality study: Stocky, muscular type; look steady, countenance cheerful, but not overemotional. Activity, good; discipline, good; willing to take chances if necessary. Stability under strain probably excellent. Good judgment.

CASE 2.—Personality rating, "B." Safe if watched for development of nervous symptoms.

——— ———, flying cadet, A. S. S. C.

Aviation history: Ground school; difficulty with wireless (has poor musical sense). 8 hrs. flying to date. No accidents.

Personal history: Nothing of importance in family history except "mother worries greatly about me" and writes to him on this subject. College graduate (4 yrs.), Harvard, A. B.; worked his way through college and has also worked in munition factory. No pronounced reasons given for choosing aviation. Unmarried.

Physical examination: Height, 5 ft. 6 in.; weight, 140 lbs.; age, 24. Nothing abnormal noted.

Tests (low tension: —.

Personality study: Short, well knit; regular features, mobile, expression tense but under control; anxious to understand and please. Manner tense and high strung. Keen sense of responsibility. Ambitious and keenly interested in his work, but inclined to take even trivial events too much to heart. Will do his duty but needs careful watching when he gets to the front. Should be watched for signs of staleness or beginning nervousness, loss of sleep, etc.

CASE 3.—Personality rating, "D." Probably not safe if flying at the front.

——— ———.

Aviation history: No trouble in ground school; work in ground school described as easy.

Personal history. Bright at bookwork; high-strung always; exceedingly popular with friends. Has had most of children's diseases; no complications nor accidents. Great interest in athletics. Public schools and college. Entered service from junior class. Unmarried.

Physical examination: Very active knee jerks. Pupils show secondary expansion, after dilatation. Height, 6 ft.; weight, 155; age, 24.

Tests (low-tension):

Personality study: Decidedly self-conscious; slightly aggressive manner; very high-strung and overemotional. Lacks normal subjective feeling of fatigue after hard exercise. Talks a great deal and rapidly. Gives the impression of working under great pressure. Is decidedly nervous and lacks voluntary control of expenditure of energy. Reserve store of energy limited. Would probably not stand strain of active service at the front.

Accompanying each history a personality summary is made on a separate slip in order to present the essentials in as brief form as possible for the use of the Commanding Officer. If more detailed information is required, this can be obtained by reference to the laboratory records.

PERSONALITY SUMMARY. No. —.

HAZELHURST FIELD, MINEOLA, N. Y.

Aviation history --

Personal history --

Physical examination --

Tests (low-tension) --

Personality study --

Rating:

Personality --

Tests (low-tension) --

A summary of the cases already examined in this department with an explanation of ratings follows.

The object of the personality study is to determine: (1) Whether neuroses or psychoses actually exist or (2) whether there are any indications in the temperament or personality of the aviator suggesting that tendencies now latent under the stress of war conditions may give rise to symptoms of nervous shock, diminishing efficiency and impairing morale.

Personality:

"A".—Safe. Nervous and mentally stable.
"B".—Safe, with limitations.
"C".—Questionable; no definite conclusion reached.
"D".—Needs special attention.
"E".—Unsafe.
Not rated.

Tests (low-tension):

"A".—No restrictions.
"B".—Should not fly above 15,000 feet.
"C".—Should not fly above 8,000 feet.
"D".—Should not fly at all.

Personality studies:

Rating "A"	46
Rating "B"	29
Rating "C"	16
Rating "D"	1
Rating "E"	1
Not rated	18
Total	111

Low-tension tests:	
Rating "A"	27
Rating "B"	26
Rating "C"	14
Rating "D"	6
Not rated	38
Total	111

Agreement, personality rating, and tests	36
Nonagreement personality rating and tests	29
One or both ratings absent	46
Total	111

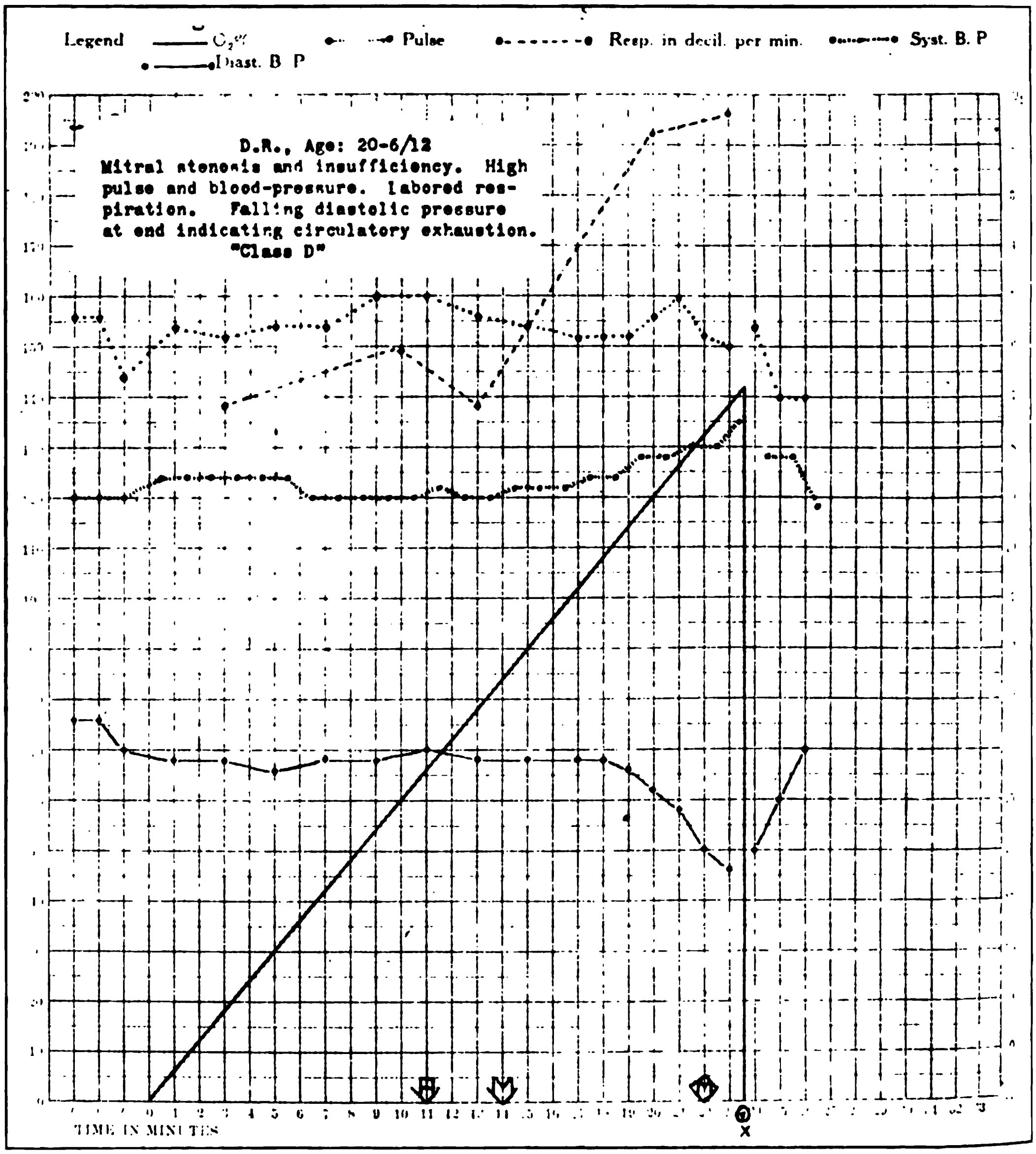
The discrepancies noted between personality ratings and test ratings are no evidences of marked differences. The low-tension tests are made with the object of determining the aviator's capacity to meet changes incident to variations in barometric pressure, whereas the aim of the personality studies is to determine, if possible, the resisting capacity for nervous and mental shocks.

In collecting this material for records great care should be taken not to suggest imaginery troubles to the person being examined. Babinski and Froment (Hystérie-Pithia-tisme et troubles nerveux d'ordre reflexi Collection Horizon. Précis de Medicine et de Chirurgie de Guerre, Masson & Cie., 1918) have emphasized the increased danger of "suggestion" as an etiological factor of nervous diseases in the life of the soldier. A great deal therefore depends upon the tact and good judgment of the examiner.

A very important function of the work of the department is to make clear the value of good mental hygiene in increasing efficiency in assisting in the maintenance of discipline on rational grounds in strengthening morale and contributing to the esprit de corps essential for a complete and final military victory.

Informal conferences on the subject of the mental hygiene of the aviator should be of practical value. The demoralizing influences of intemperance, using the word in a broad physiologic sense, the paralyzing effects of worry over unsolved personal problems, of the failure to get square with life, of anxiety about anticipated events, and the shock caused by suddenly awakening to the realization of the fact that the lure of wish-directed thoughts make an individual incapable either of judging or facing reality.

The casualty list in the Aviation Service can be greatly reduced by insisting upon the necessity of cultivating a frank, open attitude of mind in the treatment of the various problems which are forced upon the attention of the flier. Staleness, loss of confidence, various phobias, and increasing emotional instability are insidious enemies,



No. 217.—D. R. **CADET.** **Age 20 years, 6 months.**

There was a roughening of the first heart sound heard before the test. No demonstrable enlargement, second sounds equal. During the test a definite systolic murmur developed and the pulmonic second was accentuated. There is no doubt of the diagnosis of mitral insufficiently well compensated.

The chart is typical of most cases of valvular lesions. The pulse is high throughout the test. The systolic pressure is high and uniform. Diastolic pressure begins to fall between 9 and 10 per cent, but is in control at all times. Respiration shows rather a marked response. Efficiency is well preserved, the psychological note being A. This is accomplished at the expense of marked overwork of the heart. Although this is well borne at the present time, the presumption is that the subject would soon show the effects of wear, and permanent damage to the heart might easily result. Class D.

Aviators should be familiar with the methods of preventing the formation of some of the mental influences disorganizing both to temperament and character. The difficult task of keeping their nerve should not be made unnecessarily difficult by the failure to appreciate and apply a few of the principles of good mental hygiene.

HELPING THE AVIATOR TO KEEP HIS NERVE.

No one doubts the desirability of maintaining within the aeroplane and its motor the conditions essential for maximum flight efficiency. There are only a few people, however, who recognize the necessity for detecting and remedying the disturbances of the delicate nervous and mental adjustments of the aviator controlling the machine. In the air service of the allied armies the lists of casualties due to preventable and unknown causes are very much longer than the ones containing the names of aviators killed in battle. Many of these fatalities are due to the failure of those directing the activities of the aviator to take cognizance of his imperfect emotional and mental adjustments.

A long list of accidents, however, is not the only deplorable effect of the failure to assist the aviator to keep his nerve and his head in critical situations. The human machine loses efficiency much more rapidly through neglect to provide the conditions essential for good headwork than the motor does when it is not well oiled or its parts are not kept thoroughly adjusted. If even half as much care as is now given the machinery of the planes was devoted to finding out whether the emotional and mental balance of the aviator was equal to the strain to which it is subjected it would be possible to develop the fighting efficiency of the air forces to a much higher degree than exists at present.

The aviator in action has to be heart and soul in his work. Neither his attention nor interests can be divided, even for an instant.

Very brief periods of distractibility, uncertainty, or slight anxiety at critical moments may end quickly in a catastrophe. In many occupations, even in military life, these momentary lapses may not end disastrously, but the chances of their doing so while the aviator is in the air are a thousand times greater. The emotional and mental balance of the aviator should be so very delicately adjusted that it responds instantly and accurately whenever the unexpected strain of the critical situation is thrown upon it. The aviator has practically no opportunity to correct his mistakes. A wrong impulse, uncontrolled emotion, or thought not related to the situation may be the cause of disaster. This principle is equally true whether the aviator is high in the air or approaching the ground.

Disasters resulting from hesitation or indecision in the comparatively difficult though necessary procedure of landing may be and

undoubtedly are often due to a certain mental or nervous instability not generally demonstrated by the ordinary methods of observation or medical supervision. These disturbances of the mental balance are demonstrable and capable of being ameliorated by neurologic or psychiatric methods. The dangers of indecision or divided attention when in combat or even when in the usual "formations," now the rule in aerial warfare, may be easily visualized and can hardly be overestimated. In the illustration (the jackals, p. 19) the importance of maintaining position in "formation" is emphasized. This maneuver requires great mental alertness and good judgment. The danger of possible collision with other fliers in the "formation" can only be avoided by unswerving attention and coordinated and instantaneous action.

What are some of the causes which lead to momentary but often fatal inefficiency? Anxiety, worry, straining to repress harassing memories of personal trouble, a sudden and temporary but overwhelming sense of inadequacy in facing a crisis very often interfere with the transmission of the coordinated motor impulses from the brain. An aviator having an excellent record, though trying hard but unsuccessfully to repress any recollection of worry over personal problems, may lose his nerve and refuse to fly, or, on the other hand, he may attempt to fly while the mental conflict is still acute and end his career with a fatal crash. An aviator struggling hard to repress and forget these nerve-wrecking, disorganizing ideas and anxieties is a menace to himself and the whole organization until by frankly talking the matter over with some sensible person he "gets it off his chest." The first step in the restoration of efficiency and nerve consists in facing squarely the real cause of his anxiety instead of trying to evade it.

Even the aviator who is mentally and physically fit, may be thrown into a condition of mental irritability and anxiety, which he is not able to control, upon the receipt of depressing, unreasonably solicitous, or even threatening, letters from home. Frequently states of apprehensiveness and anxiety affect the aviator to a far greater extent than he realizes or is willing to admit even to himself.

There are different types of personality which, on account of their special intellectual qualities, are now generally recognized as possessing the temperamental qualities antagonistic to success in aviation. Among the types which require special supervision are men with decided variations in mood or emotional tone. We all know men, in our own circle of acquaintances, in whom such variations are marked; men who may be classed at times as extreme optimists, at other times swinging over to the opposite or pessimistic pole of emotional experience. Within certain limits and under intelligent medical super-

vision, this group of men may, and probably do, furnish some of the most versatile and daring of the aviators. On the other hand, we are confronted by the fact that these same men if permitted to swing to the extremes of the emotional arc will certainly become casuals or casualties. They may develop on the one hand into the cases of unbalanced manic-depressive make-up, latent hysterical trends, and many cases showing symptoms of the anxiety neuroses.

The question of mental hygiene, as related to the aviator, should be given a great deal of attention. The reduction of the efficiency of the soldier through any form of intemperance is now generally recognized; and similar effects, but to a far greater extent, are observed in the case of the aviator. The type of man making the successful aviator is often high strung and impulsive and requires plenty of outlet for his energies. These outlets can be easily provided in ways entirely satisfactory to him and conducive to his efficiency without injuring the brain and the nervous system as does dissipation. He, himself, does not seek dissipation; but, having an enormous amount of unexpended energy, he seeks some channel—any channel—for its discharge. Adequate provision should, therefore, be made for recreation and suitable forms of mental relaxation if the dangers of dissipation are to be avoided.

The supervision of the aviator outlined above has been definitely included as a part of the duties of the Flight Surgeons. It is planned that the Flight Surgeons shall receive instruction and advice relative to the methods of observation and examination of the fliers at the Medical Research Laboratory or other centers of instruction. That specialists in psychiatry can not be trained in the short time available is clearly recognized. On the other hand it is possible for the Flight Surgeon to obtain a certain point of view toward his problem and for him to become definitely informed concerning the types of personality referred to in the preceding paragraphs. The problem of the training of the Flight Surgeon therefore resolves itself into one of method of observation and examination.

The neuro-psychiatric examination is brief; sufficiently brief to get it all on one page. First is given an account of the aviator's entrance into the Air Service, of his aviation school work, and the chief causes which led to his selection of this branch of the service. It is important to know whether the choice of this branch of the service was made voluntarily and enthusiastically; whether he drifted into it and is more or less indifferent or even unhappy in it. Then follows an account of his Army life preceding his entrance into aviation. Finally in this part of the investigation a note is made of the number of hours of flying, and also whether there have been any accidents. A brief personal history follows the family history, with reference to the diseases or injuries he has had. Com-

paratively slight disorders may be the cause of great harm. Tonsillitis is an example. Attention is paid to his school and college record, with mention of his athletic record. These data tell us something as to the sports in which he was proficient and give us a fair idea of his skill as well as of his temperament qualities.

The attitude of the family, especially the mother and wife, are noted, whether it is one of sympathetic approval or disapproval, and this has an important influence upon his capacity to keep his nerve. We also try to ascertain whether he has definite cause for worry. Sometimes there are periods when the aviator prefers not to fly, but, on the other hand, he is usually very keen for his work, and it is only when something has gone wrong that his enthusiasm wanes; sometimes disturbing influences emanate from home; sometimes he feels "fed up" and wants a holiday. Many influences, both internal and external, may, if powerful at the critical moment, throw him off his mental balance. The aviator's balance and alertness must be maintained at the highest efficiency while he is flying. At intervals, when for any reason his full potential efficiency is not maintained, he should not fly nor until he is again at his best, both physically and mentally. Great tact should be exercised in gathering the data. A great deal of information of importance, often of a personal nature, would not be divulged unless the examination brought it easily to light and demonstrated to the aviator its importance.

Third, a brief physical examination is made. The reactions of the pupils and extrensic muscles and the knee jerks for evidence of hypertension or hyperexcitability are recorded. Sometimes we get signs of fatigue in these reactions; sometimes signs of emotional hyperactivity. The presence of tremor in the extension of the hands and in the handwriting, as well as in the process of drawing horizontal and vertical lines freehand, is also mentioned.

Tests for dermagraphia before and after flying or before and after the rebreathing tests are made. Definite conclusions relative to these tests have not been reached as yet, but our attention has been drawn to certain groups of symptoms. We have looked upon a tendency of the line to spread or blotch as rather connected with other signs of fatigue and disability. This reaction is frequently accompanied, though not always, by nervous, very lively knee jerks and an emotional instability. A secondary pupillary reaction is sometimes associated with this group of symptoms.

Occasionally after the rebreathing or after flying a blushing is observed a finger's width on either side of the line. This seems to be of more or less importance, taken in conjunction with the other symptoms mentioned. But whether this deduction can be borne out by further observation remains to be seen.

Lastly, we record our impression of the aviator's personality. We observe whether he is open and frank in his talk or reserved and inhibited. We note his emotional state, trying to determine whether he is in a contented frame of mind or whether he is disgruntled and does not want to say so or whether he is "fed up." It is important to determine as closely as possible what the reason is that he is on edge or out of sorts. With this object in view, a record is kept of even slight fluctuations of moods.

Frequently we run across men in a state of mental anxiety mild or acute. A little tactful questioning will usually bring out the causes. These causes may be simple and easily removable, or they may be complicated and persistent. The points bearing on the case must be talked over frankly and conscientiously. Late hours, loss of sleep, too many cigarettes will easily lower the resistance. Worry and anxiety of any sort in the otherwise perfectly healthy and well-set-up man will surely reduce his efficiency. Even steady attendance upon his work to the point where he is "fed up" will, if persisted in, produce signs of mental and nervous strain and soon render him a danger in the air.

In a short study of the personality we determine whether the flyer is aggressive or on the defensive, whether he has initiative and courage or is reckless and irresponsible, whether he makes quick or slow decisions, whether he is a high-pressure engine under control, and whether his judgments are likely to be good. His reactions during the examinations are important. He may give active cooperation, and this is a good sign, or he may leave us with the impression that the result of the examination was unsatisfactory; even this indefinite finding may later have an important bearing on the personality study and should be recorded. These and other items help us to gain a fairly definite impression of our man.

Nervous states nearer the border line of the psychoses are occasionally observed. The importance of detecting these cases and weeding them out is apparent, and we should appreciate how easily they may escape recognition. Many cases which under conditions of ordinary life do not develop into psychoses in all probability will take this unfavorable turn under the strain and stress of war.

Our whole object is to determine any undesirable psychomotor or other reaction that indicates that the man is wholly or in part unfit for flying. We accomplish this in as brief, direct, and practical a way as possible. After the examination the man is classified according to estimated efficiency, judged from the neurologic and psychiatric point of view. The classifications are A, B, C, D, E.

Explanation of personality rating:

A=Safe, nervous, and mentally stable.

B=Safe, with limitations.

C=Questionable; no definite conclusion reached.

D=Needs special attention.

E=Unsafe.

In order to illustrate some of the different types and give an indication of the methods of making personality studies the following cases are cited:

PERSONALITY RECORD.—No. 194.

WHITE FIELD, N. H., *June 3, 1918.*

H. R. S., 1st lt., RSSR., pilot.

Aviation history: Officers' Training Camp June to July 30, 1917; ground school to Aug. 5, 1917; to E. Field to Dec. 20, 1917; to J. Field March 31, 1918; commissioned Feb. 6, 1918; to S. Field to date. 260 hrs. flying to date. No crashes.

Personal history: Measles and scarlet fever, good recovery. Appendicitis 1915, operation successful. Father dead, age 53, chronic nephritis; mother living and well; 1 sister living and well. Mother does not approve of aviation, believing it too hazardous for her son. Mother's concern has "modified his actions; more careful." This is doubtful. Not particularly athletic. Education, high school and college.

Physical examination: Ht., 69; wt., 136; age, 24. Knee jerks active. Fine tremor in fingers, constant; pupils react normally to light and accommodation. No secondary dilatation.

Personality study: Quiet, some reserve; has to be interested in flying to follow it or make it a success; deeply interested in flying; anxious to get across; "getting tired of wasting further time in training." Was disappointed three weeks in not being transferred to Columbus and in not getting leave of absence. Wants aerial gunnery; has had 100 hrs. formation; getting disgusted; feels physically tired from continued flights and frequent trips to New York. (Impatient.) Emotion easily excited toward end of examination.

Rating: Personality, "E." Tests, low-tension.

PERSONALITY RECORD.—No. 207.

Station ———, Date ———.

B., R., 2d lieut., — squadron, pilot.

Aviation history: Enlisted aviation section Sept., 1917; graduated from ground school Jan. 20, 1918; Kelly Field, San Antonio, Tex., to June 10, 1918; to R. F. to date. 150 hrs. flying to date. 2 accidents. 2 crashes, both from low altitude in high wind, 2 days following first solo flight. Not injured.

Personal history: Father and mother alive and well. Glad to have him in aviation. Athletic training, track, basketball, horseback, mountain climbing. 6 to 10 cigarettes daily, not inhaled. Education, high school, university 2 yrs. Civil occupation, civil engineering. Unmarried. Res., Ogden, Tex.

Physical examination: Ht., 66; wt., 125 (usual weight); age, 24. Pupils normal to light and accommodation. Tonsils operated in childhood; visible stumps, enlarged cervical glands. Knee jerks lively. No tremor of hands.

Personality study: Wears an expression of slight apprehension. Looks tired, a little pale, and not fit. Says he turns in at night at 12 or 2 usually. Nearly fainted yesterday while being examined (at medical department).

He seems direct and frank, but I can not feel sure of this. Gives the impression of being mentally and physically tired. Should be seen again and certainly not to fly at present. He realizes he is not in best of condition. Can not say positively there is any psychic evidence of his lack of condition. May be due to tonsils.

Rating: Personality, "E" (temporarily on account of tonsils and fainting).

PERSONALITY RECORD.—No. 198.

BLACK FIELD, Date ——.

J., H. Q., 1st lt., ASSRC., pilot.

Aviation history: Ground school July 1st, 1917, to Oct. 1, 1917; transf. to Black Field to May 30, 1918. 315 hrs. flying to date. No crashes.

Personal history: Typhoid at 13 yrs. Fractured right humerus near shoulder joint, 10 years ago. Athletic training, foot and base ball, swimming, tennis; always in training. Education, 4 yrs. high school, 3 yrs. college. Unmarried. Res., Philadelphia, Pa.

Physical examination: Ht. 70; wt., 154; pulse 64, high tension; pupils, equal active, slight secondary dilatation; knee jerks; active, easily exhausted.

Personality study: Has been flying constantly since last year; has felt feeling of staleness; "loss of pep" for 1 month. No worries or fears, merely the wearing of the steady grind, no variety; at present only formation work. Quick, accurate responses. Wants change; rest for a week or two. Should be watched during convalescence period. Optimistic as to future. Increased motor activity; sweating localized; face flushes easily. Has dreamed of flights only recently; of being in tail spin.

Rating: Pensonality, "E."

PERSONALITY RECORD.—No. 204.

—— Field, ——.

P. J., 1st lieut., pilot.

Aviation history: May, 1917, Tech School, X Field—to date. 70 hrs. flying to date. No crashes.

Personal history: Measles, pneumonia, and recurring tonsillitis until this year. Broken leg 2 yrs. ago. Father living and well, 1 sister living and well. Family firmly opposed to flying. Wife greatly depressed over aviation. 2 small children. Married. Res., New York, N. Y.

Physical examination: Ht., 68; wt., 165; age, 25. Knee jerks; very active. Pupils react normally to light and accommodation. Slight secondary dilatation after primary dilatation, after primary contraction.

Personality study: An excellent type; open frank, genuine forceful, courageous. Has personal worries and has good cause for them.

Rating: Personality: "E."

PERSONALITY RECORD.—No. 189.

E. FIELD, *June 29, 1918.*

S. E. J., 2nd lieut., pilot.

Aviation history: Ground school July 17–Jan. 18, 1918. O. Field, Feb. 6, '18–May 30, '18. M. Field, to date. 310 hrs. flying to date. No accidents.

Personal history: Measles and malaria during childhood; typhoid at 15, pneumonia 16. Athletic training, football, basket ball, and track. Education, high school, 2 yrs. college. In Army since 1915. No leave.. Tobacco, 15 cigarettes daily. Alcohol, moderate. Family, father and mother living and well; 3 brothers living and well. No opposition. Unmarried. Res., Rock Hill, Ark.

Physical examination: Ht., 71; wt., 174; age, 23. Can't relax so it is difficult to obtain knee jerks unless attention is diverted. Pupils active. Marked secondary dilatation.

Peronality study: Feels stale and shows some emotional instability. Says he has not had an accident, but knows one is coming. Probably does not take very good care of himself. Is unsafe for flying on account of present condition. Should have vacation.

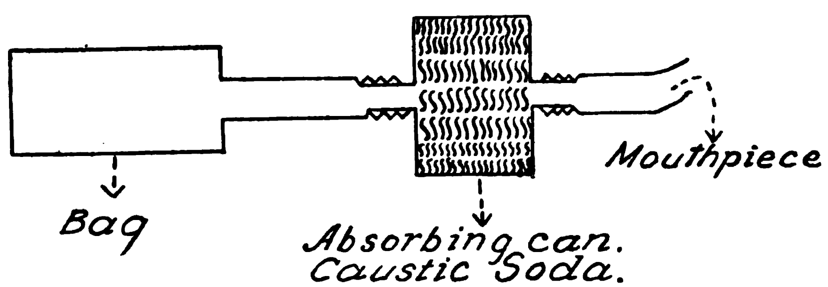
Rating: Personality: "D."

VIII.—THE REBREATHING MACHINE.

The rebreathing machine in its simplest form consists of a bag filled with air, connected by a tube to one side of an absorbing can containing caustic soda (see fig. 1). A tube leads from the other side of the can to a mouthpiece. A clip having been placed on the subject's nose and the mouthpiece in his mouth, he breathes into and out of the bag, the air passing through the caustic soda, which removes from it all of the exhaled carbon dioxide. Inasmuch as a part of the oxygen contained in each breath is absorbed by the body and the carbon dioxide is removed by the caustic soda, the volume of air in the bag gradually decreases and the percentage of oxygen in the mixture grows progressively less. Starting with 60 liters of air in the bag, the average subject will reduce the oxygen to 7 per cent in about 30 minutes.

SIMPLE FORM OF REBREATHING APPARATUS.

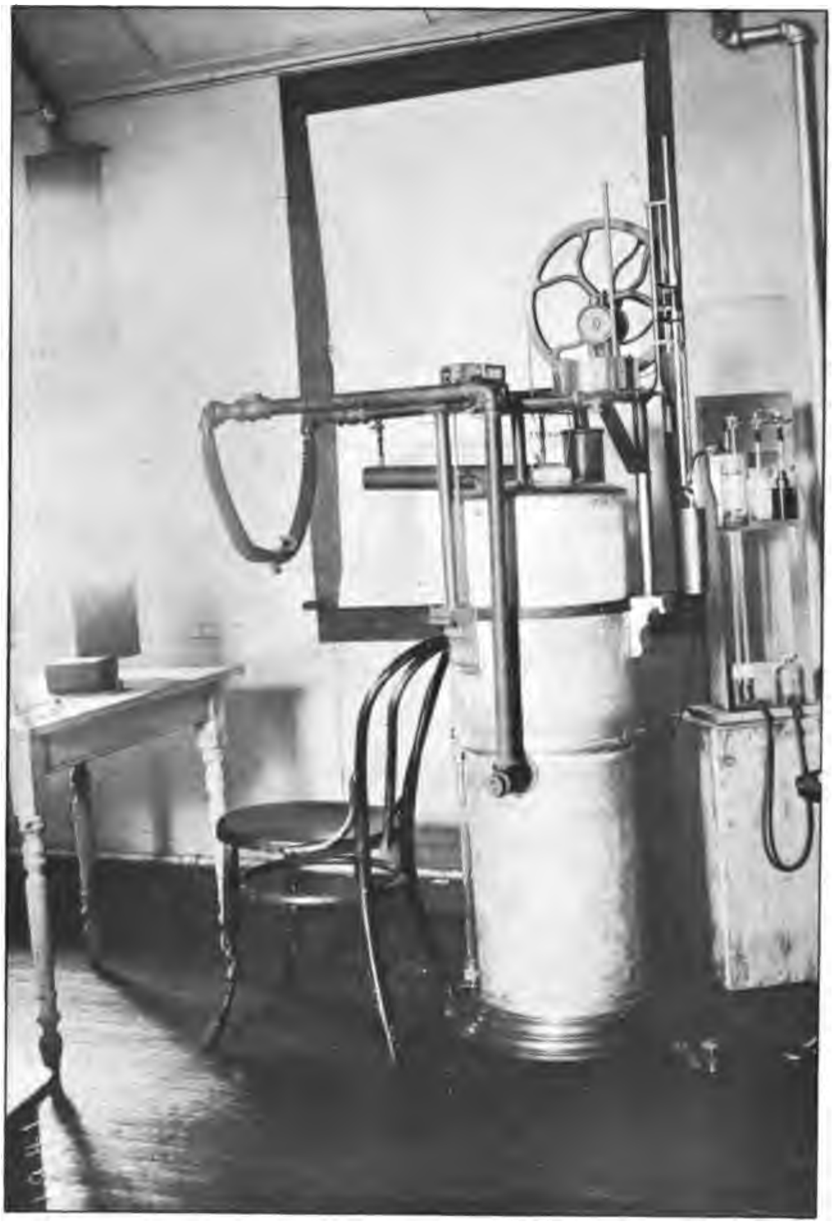
The rebreathing machines in use in the laboratories of the Medical Research Board embody the same principle as the simple apparatus shown above, but they are built of metal and are designed particu-



SIMPLE FORM OF REBREATHING APPARATUS.

larly for the routine testing work of the board. There are at present three forms of the machine in use, called respectively type A (serial Nos. 2–13, inclusive), type B (serial Nos. 14–22, inclusive),

THE REBREATHER.

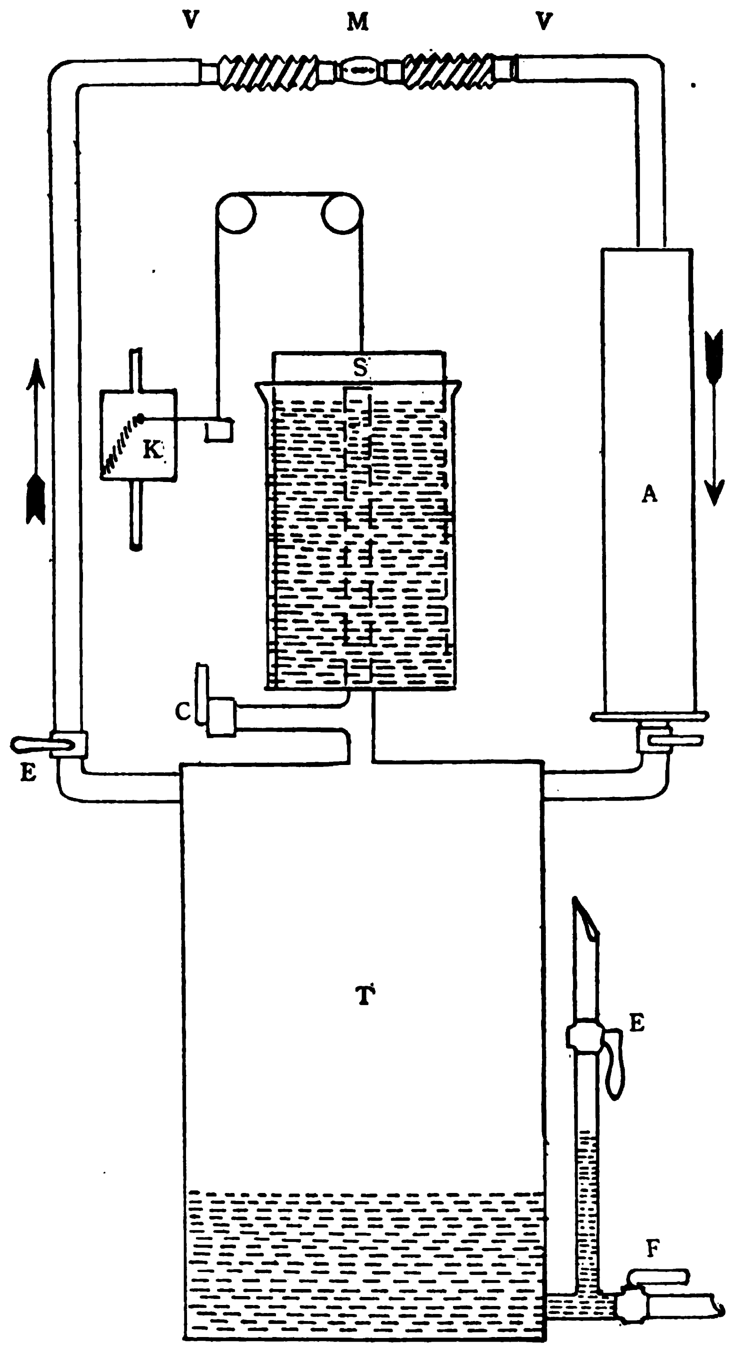


and type C (serial Nos. 23–37, inclusive), but they differ only in details and a description of one will serve for all (see fig. 2). The base of the machine is a steel tank (T) of 60 or 80 liters capacity, according to the type. Type A has 80-liter, and types B and C 60-liter tanks. Air is inspired from the tank through the pipe at the left, and is expired back into the tank through the pipe and absorbing cartridge (A) at the right. The valves (VV) keep the air stream flowing always in the proper direction. In order to maintain the contained air at approximately atmospheric pressure and to allow for changes in volume, a wet spirometer (S), carefully counterbalanced, is mounted on the tank and communicates freely with its interior through the vertical pipe (P). A stylus attached to the counterweight records the movements of the spirometer upon the smoked drum of the kymograph (K). Water is admitted to the tank through valve (E) to replace the volume of the used oxygen and also to flush out the tank after an experiment. The water is drained away to the sewer by means of valve (F). Valve (C) affords a free opening to the atmosphere for flushing the tank of the rebreathed air. Valve (D) should invariably be closed while flushing the tank, otherwise water will enter the absorption cylinder (A) and ruin the cartridge. The cartridge is a cylindrical paper tube filled with solid caustic soda, cast in thin shells so as to expose a large surface to the action of the gas. It is prepared for use in the machine by punching the ends full of quarter-inch holes with a pencil. The brass ring is then inserted in the lower end of the cartridge, the rubber ring fitted over the end, and the whole inserted into the absorption cylinder. Cartridges should never be used without both rubber ring and brass ring in proper position. Valve parts may be removed from the air valves (VV) by means of the brass spanner wrench, which, together with two new valve parts, is furnished with each machine. Counterweight slide rods should be frequently greased with vaseline and the pulleys oiled. In setting up a machine care should be taken to level it properly, so that the inner can of the spirometer hangs freely in the outer can and does not rub against the side.

IX.—THE LOW-PRESSURE CHAMBER.

The low-pressure chamber at the Mineola laboratory is a cylindrical steel tank, 8 feet in diameter and 10 feet high, standing on end. It is entered through a full-sized doorway in the side, and forms a commodious and comfortable room in which five or six investigators may conduct physiological, psychological, and ophthalmological tests under conditions of reduced atmospheric pressure.

The reduction of pressure is brought about by means of a motor-driven vacuum pump of 10 horsepower, capable of rarefying the atmosphere within the chamber to a barometric pressure of 140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millimeters of mercury (equivalent to 35,000 feet above sea level) in five minutes. This is more than sufficient for any tests upon human beings.

The pump withdraws air from the tank through a 3-inch pipe at the top; at the same time fresh air is admitted at the bottom, the amount being regulated by means of a valve. The admission of air in this manner serves the double purpose of ventilating the chamber and of determining the rate at which the pressure is reduced. That is, if the valve is wide open, pressure remains normal; if the valve is closed, the pressure drops rapidly. Thus by manipulating one valve any rate of pressure rise or fall may be secured.

The inside of the chamber is finished in a flat, neutral tint and lighted by tungsten "daylight" lamps. Several windows of thick glass allow experiments to be watched from without.

An oxygen supply is piped through the wall into the chamber to a distributing board, with an individual tube and mouthpiece for each observer. A check valve in the pump line prevents a material drop of pressure within the tank if, for any reason, the pump is stopped.

For ease and efficiency of operation the control has been centralized. Directly before the operator is a small window and a telephone, enabling him to observe and communicate with those inside. At the left of the window is the mercury manometer indicating the barometric pressure within the tank, expressed in millimeters of mercury and in feet above sea level. At the operator's left hand are the valves regulating the oxygen supply; the valves at his right hand control the flow of air, and below them is the switch for the motor. The operator need not leave his post from beginning to end of an experiment.

Figure 12 is a view of the chamber.

X.—THE CLASSIFICATION EXAMINATION.

The test for classification of aviators is an outgrowth of the research work on the physiological effects of low atmospheric pressure. It was found that there were wide variations in the resistance to such effects, and the task was undertaken of determining which individuals were most suitable for the branches of work which involve flying to the higher altitudes.

The method of rating adopted corresponds well with the military needs of the service. In the first place are the fighters, the pursuit pilots, who commonly fly about 15,000 feet, often above 20,000 feet. In the second, the bombers, who fly comparatively high but rarely above 15,000 feet. Third, the observation planes keep mostly in the lower levels, rarely going above 8,000 or 10,000 feet. The results of

the low-oxygen test are expressed in ratings A, B, and C, corresponding to the above requirements. Class D includes men who for one reason or another ought not to fly at all; such cases are occasionally found, though the purpose of the test is classification of flying personnel rather than elimination of any. After several hundred tests have been made it was found that the number of men passed in class A (about 50 per cent) was much greater than the need of the service for pursuit pilots. Since choice had to be made among these men anyway, it was felt that a still higher rating was desirable which should include the particularly hardy specimens who ought by all means to be chosen first. For this reason a rating of AA is given to about 10 per cent of men examined.

The examinations are being made at the central laboratory at Mineola and at a number of the flying schools in this country. It is hoped later to send examining units to every flying field here and abroad, and also to make the examinations at an earlier period in the career of the flier by installing examining units at ground schools or other concentration points for candidates.

The examining unit consists of four officers and six enlisted men. The officers are a physiologist who has general charge of the conduct of the test and sees that the technical details are carried out; a clinician who passes on the general physical fitness of the subject both before and during the test, especially on the reaction of the heart and circulation; a psychologist who determines the effects on general efficiency as expressed by the apparatus work; and an ophthalmologist who makes a careful preliminary examination of the eyes and determines any effects of low oxygen upon the vision. The enlisted men manage the rebreathing machine, make air analyses, record pulse and blood pressure during the test, and do the clerical work on the reports.

The routine test is carried out as follows: A careful history is recorded and a general physical examination made, special attention being given to the circulatory apparatus. The reaction of pulse and blood pressure is measured when reclining and standing, after standard exercise (stepping up five times upon a chair), and two minutes after exercise. It is hoped that these simple tests will be found useful when repeated later in the career of the flier to determine whether he has remained in good condition. It may be stated that a normal behavior in these reactions has been found to be a very fair index of the subject's ability to pass the low-oxygen test. A careful examination is now made of the eyes.

The next step is the rebreathing test itself. The evidence is sufficient that this test is a perfectly reliable index of tolerance to low atmospheric pressure, and the low-pressure chamber has been used

not as a routine method of examination but only as a means of checking up the results of the other test and for scientific purposes.

The rebreathing machine is so adjusted that the average run will be between 25 and 30 minutes. During the run the subject does the psychological work as described elsewhere and is carefully observed by the psychologist to determine the earliest effects on attention and motor coordination, as well as the time of appearance of more marked effects and of total breakdown.

Every three minutes the capacity of the external and internal ocular muscles is retested during the run (near point of convergence and near point of accommodation). During the whole test the pulse and blood pressure, systolic and diastolic, are measured every one or two minutes. The clinician keeps close watch of these figures and makes frequent examinations of the heart. The respiration is recorded during the test on a kymograph.

The test ends when the psychologist has determined that the subject has reached the point of complete inefficiency, or when the clinician finds that the condition of the circulation makes prolongation of the test undesirable. The latter contingency usually means either that the heart is abnormal or that fainting is about to occur unless the test is stopped. At the close of the run the air remaining in the apparatus is analyzed to determine the oxygen percentage reached, which can be translated roughly into terms of altitude. A few subjects have exhausted the oxygen to 6 per cent or a little lower; 7 per cent is a frequent figure, while poor subjects either become inefficient or faint at considerably higher percentages.

The results of the test are summarized in a plot of which the abscissa line represents minutes of time, and the ordinates are per cent of oxygen, and figures representing pulse, blood pressure, volume of respiration, millimeters of near point of convergence, etc. The appearance of different degrees of inefficiency by the psychological tests is indicated by symbols placed at the proper time on the abscissa line. It is assumed (with reasonable correctness) that a straight line connecting the oxygen per cent at beginning and end will represent the per cent at all intervening times. The basis of judgment on the success of the subject is the oxygen percentage at which various phenomena occur, and this is reckoned from the height of the oxygen line at the time in question.

The decision as to rating the subject is made by consensus of opinion on the basis of the ratings made by each separate department and is ordinarily the lowest rating assigned by any one of them. No man is passed in class A who has any considerable disqualification from any point of view. For example, a deficiency in vision whether ordinarily present or only developing as the result of the test would dis-

qualify for combat work no matter how well the candidate performs otherwise.

Aside from ocular deficiencies or general physical conditions of a distinctly abnormal nature, the rating of a subject depends on the answer to two questions. How well does he adapt himself to the unusual environment, i. e., how well does he preserve his efficiency at altitudes (as expressed by the psychological tests) and, second, at the expense of how much strain on his circulatory system does he do it? Many subjects will compensate admirably, preserving their efficiency to a very high altitude, but only by means of a very high blood pressure, high pulse, or violent vasomotor reactions such as would lead us to expect that this man would wear out quickly in service or, perhaps, actually have a circulatory collapse in the air and faint.

As to the first question, that of general condition and the proper functioning of the compensatory apparatus, our most delicate criterion is the performance on this psychological test. If a man is able to keep his brain clear, he is certainly compensating against low-oxygen effects, for the brain is not only the most important tissue to protect, but it is also the most sensitive to defective nutrition. After much experimentation with different systems of rating a fairly empirical method of computation has been adopted (fully described elsewhere) which takes into account the percentage of oxygen at which various effects appear and the duration of the test, since longer exposure to moderate oxygen deficiency may produce more profound effects than a short exposure to a high degree. The rating is based both on the early slight signs of abnormal effect and on the more pronounced manifestations up to complete inefficiency. One man may be moderately inefficient from 8,000 feet up, but only break completely at 25,000 feet. Another may remain perfectly clear until 20,000 feet and then suffer a complete loss; probably the second man would be a more useful flier than the first.

The second question, that of the amount of circulatory strain involved in preserving compensation, is answered largely by the behavior of pulse and blood pressure and by the sound of the heart during the test.

A fuller discussion will be found elsewhere of the method of rating based on circulatory effect. A subject who has a definitely diseased heart, no matter how well compensated, is put in class D, and it is recommended that he be kept at ground work. No man is passed in class A whose blood pressure is so high that the heart will be continually undergoing severe strain. Signs of circulatory exhaustion or fainting are causes for rating in class B or C.

It should be stated that some of these circulatory reactions are signs not of constitutional inferiority but of temporary lack of condition. They none the less give a clear index of how the man may

be expected to behave in the air, and such a temporary rating should be followed until a better general condition can be demonstrated. It is hoped that it will be possible to apply the test at rather frequent intervals to the aviators in service and thus determine whether they are remaining in good condition or becoming "stale." For this reason it has been arranged that the report of the examination is to accompany the aviator wherever he goes and be accessible to the Flight Commander and the Flight Surgeon.

An analysis has been made of the results of 374 routine examinations. The results are given in the tables below.

The first table shows the percentages of the various ratings among various classes of subjects examined. Pilots and cadets show almost identical figures for the higher ratings, but more absolute disqualifications were recommended among the latter. Nonfliers make a considerably poorer showing.

TABLE No. 1.—*Analysis of 374 examinations.*

	AA		A		B		C		D		Total.
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	
Pilots	15	9.4	52	32.7	58	36.5	32	20.1	2	1.3	159
Cadets	16	9.7	54	32.7	58	35.1	27	16.4	10	6.1	165
Total fliers	31	9.5	106	32.7	116	35.9	59	18.2	12	3.7	324
Observers	1	4.3	5	21.7	6	26.1	10	43.5	1	4.3	23
Others	1	3.7	7	25.9	7	25.9	7	25.9	5	18.5	27
Total	33	8.8	118	31.7	129	34.6	76	20.3	18	4.8	374

The average age of the various classes is interesting. This was tabulated for 193 cases passed above D.

TABLE No. 2.

	Number.	Age.	
		Yrs.	*Mos.*
Class AA	22	23	9
Class A	61	25	1
Class B	69	25	1
Class C	41	24	7

Among 109 cases of fliers rated class B the reason for not giving A was as follows:

	Number.	Per cent.
Circulatory exhaustion	37	33.9
Psychic deterioration	36	33.0
Both of above	27	24.8
High blood-pressure	9	8.3
Total	71	100.0

condition demands it, the subject should be removed before this time. The necessity for interrupting the test before its natural termination is to be decided by the clinician though all others present should call his attention to unfavorable indications. This applies especially to the physiologist and the enlisted man taking pulse and blood pressure, who should promptly report to the clinician any noteworthy change in these observations or in the respiration.

5. No test should be prolonged beyond the point where the final rating can be determined. For example if the subject's heart puts him in class C or D, it is a matter of no great interest whether he ranks A or B on the psychological test. It is important that the test be so conducted that subjects will not have the expectation in advance of undergoing anything dangerous or disagreeable; for this reason tests should rarely be prolonged to the point of fainting, unconsciousness, or great discomfort.

6. All members of the unit must exercise diligent care to prevent the prejudicing, alarming, or exciting of the subject. This applies not only to subjects being tested, but to all fliers and candidates who may be later subject to test. Even chance remarks, which might give the impression that there is danger or discomfort in the test, or that many men are disqualified as a result of the test, must be scrupulously avoided. Unfortunate remarks which seem unimportant to the person making them, do in many cases produce such an effect on the subject that his performance on the test is materially modified.

7. Instructions to the aviator concerning the operation of the psychological apparatus, will be given by the psychologist only. Additions by other members of the group are detrimental.

8. During the first three minutes of the run, the aviator will be coached by the psychologist.

9. Stop-watches of the psychologists, ophthalmologist, and cardiac observer will be started simultaneously, and all records will be kept in terms of elapsed time after watches are started.

10. Beginning at the sixth minute, and at three-minute intervals thereafter, the psychological work will be stopped for 30 seconds, to allow the ophthalmological and cardiac examination. It is important that the ophthalmologist keep track of the time so that he shall be ready promptly.

11. Full instructions as to the ophthalmological tests must be given previous to the commencing of the run, so that no instructions will be necessary in the 30-second period.

12. In case the clinician feels that the subject's physical condition demands more frequent examinations these shall be made in such a way as to disturb the psychological test as little as possible.

13. Rebreathing tests may be made separately for the purposes of the different departments, but in rating fliers a single test will be made as a routine. If it seems desirable an unsatisfactory test may be repeated.

14. Results should not be indicated to the aviator except in the most general form—especially to be avoided is any statement of "how far he went" in terms of thousands of feet altitude. It may be made plain there is no direct parallel between oxygen percentage in the rebreathing test and low atmospheric pressure, and that in the rapid progression of the test the results would be very fallacious if applied to active working conditions at high altitudes.

15. The duties of the officers are:

(*a*) The physiologist will have immediate charge of enlisted men A and B, see that their work is being done properly, that all apparatus is in order, and that necessary supplies are kept in sufficient stock. He will take pulse and blood pressure before the rebreathing test in the manner prescribed on page 2 of the history. He will pass on the character of the pulse, respiration, and blood pressure, conferring with the clinician as to their bearing upon the normality of the circulatory apparatus. He will enter this judgment on these matters under "summary" on page 2 of the history.

(*b*) The clinician will carefully read the history prepared by enlisted men C; go into more detail as to points suggested, especially as to the exact condition at time of test. He will then make a physical examination and fill in the entries on the history form or dictate them. He will be present at each rebreathing test, following carefully the condition of the subject, interrupting the test if he considers that the subject's physical condition demands it, being the one man responsible for ending the experiment. On completion of the test he will enter on the blank (p. 3) the exact condition at beginning and at close of test (especially whether unconscious, fainting, etc.), note manner of recovery, and any other remarks as to progress of test. He will summarize on page 2 the behavior of the subject's general physical fitness both before and during the test, especially the behavior of the heart. He will consult with the physiologist as to respiration, pulse, and blood pressure.

(*c*) The ophthalmologist will conduct preliminary tests, and tests during the rebreathing experiment. He will base his rating on the results of both tests.

(*d*) The psychologist will observe the performance of the subject during the test. He will plainly signal to the clinician when he is ready to terminate the experiment, and the clinician will ordinarily take the subject off at this time. He will base his rating on both the preliminary performance and on performance under low oxygen.

16. The duties of the enlisted men are as follows:

A will have the care of the rebreathing machine during the test and will be responsible that it is kept in order. He will make analyses and record them on the history sheet, page 3.

B will take and record pulse and blood-pressures during the test and attach this record to the history sheet. He will fill in the names at the top of page three of the history. He will be responsible that all papers are taken to be plotted as soon as above entries are made.

C will receive candidates, give them directions as to procedure, take their history, assist physiologist and clinician in their examinations. He will also assist E with copying and keeping in order the histories.

D will be responsible for making three copies of the charts in each case.

E will be clerk, writing such letters, etc., as may be ordered, and being responsible that three identical copies of each record are prepared, and that they are mailed after approval to their appropriate destinations.

F will have charge of the psychological apparatus and will manipulate the lights during the test. He will assist in the plotting and copying.

17. The Commanding Officer of the unit may readjust the assignments of the enlisted men as he deems wise; e. g., A and B should be interchangeable, and it may be necessary that C, D, and E assist each other somewhat.

ROUTINE FOR RECORD KEEPING.

1. Candidates will report to enlisted man C.

2. C will enter candidate's name in the journal, take the history and attach to it the check slip. The history (original copy) will be either written in ink or typewritten. The two copies will be typewritten. Entries by the various departments are to be made only on the original and the original is to be signed by each officer, military rank being added and designation as "Physiologist," etc.

3. Each step afterwards is to be initialed on the check slip as it is made.

4. Preliminary pulse and blood pressures to be taken by the physiologist.

5. Physical examination to be made and entered (or dictated) by clinician.

6. Preliminary eye examination made and entered by ophthalmologist.

7. History to go to rebreathing room with the subject, to be delivered to B. B is to be instructed that no test is to proceed until the history is in his hands and until all procedures up to this point are checked on the check slip.

8. At the close of the test the names of observers are to be entered by B; any remarks about the test may be entered by the physiologist or the clinician; the clinician will enter condition at beginning and close of experiment and at this time he will usually enter his remarks, under the summary on page 2. The air analyses will be entered by B, who obtains them from A, as well as the exact time of day and the duration of the test.

9. At the close of the test all papers (history, check slip, pulse and pressure notes, duplicate of psychologist's notes, kymograph tracing) are pinned together and taken to plotting room by B, and placed in folder marked "Plotting room. To be plotted."

10. Three identical plots are made by D.

11. D takes all papers to ophthalmologist's desk and places them in folder marked "Ophthalmologist. For notes on histories." Ophthalmological data are to be added to chart and entries made under summary on page 2.

12. Papers taken in turn to similar folders on desks on psychologist, physiologist, and clinician, who similarly make their additions to chart and history.

13. Each department should attend to this clerical work as expeditiously as possible, and see that papers are forwarded at once to the next department.

14. When notations are complete all papers are to be placed in basket on C's desk marked "Examination complete. Plotted. Notes made. To be rated."

15. A conference of all officers on rating is to be held at frequent intervals, preferably each day. The rating is decided on concensus of opinion, being ordinarily the lowest rating of any department. The subject is to be assigned to one of four classes, viz: A (no restriction as to altitude), B (should not fly above 15,000 feet), C (should not fly above 8,000 feet), and D (should not fly at all). Further recommendations of the board in greater detail will at this time be dictated to E, who will later see that such entry is made. It is desired that recommendations be made as explicit and detailed as possible, advising as to the exact kind of work the subject can do best.

Entries under recommendations of the board should be made in language understandable to the laity. (In the rest of the report this is not important since the data is primarily for reference on repeat examinations or for collation.) The definite figures established as to altitude are to be given as above. It is a good usage to explain by a phrase or so all ratings below A. For instance, if the psychologist gives a rating of B, the following phraseology may be employed: "Class B (should not fly above 15,000 feet), becomes inefficient before highest altitudes are reached." In case of heart strain:

"Class C (should not fly above 8,000 feet). Preserves his efficiency at moderate altitudes only at the cost of severe heart strain. Would wear out soon if used at high altitudes," etc.

16. Records to be returned to basket marked "Rated. To be copied."

17. E will see that three copies are prepared, identical, except that only the original need be signed. He will then return them to basket marked "Copied. To be inspected."

18. Reports will receive final inspection of Commanding Officer of unit, whereupon E will send the original to the Commanding Officer of the flying field, one copy to office of the Surgeon General, United States Army, and one will be filed in the Medical Research Laboratory. (For the present all three copies and all other papers will be sent to the Medical Research Laboratory at Mineola, where they will be inspected and distributed as above. When this is done, it will be advisable for the unit to keep on file duplicates of the original notes. When the original is sent direct to the Commanding Officer of the flying field and is thus on file at the field, the unit will not need duplicates.)

19. In filing records in Medical Research Laboratory each one as it arrives will be given a serial number and all papers marked with this number placed in a manila folder also marked with name and number, and filed serially. A smaller (3 by 5) card will be made out for each record and kept in a smaller file in alphabetical order.

20. In case the examination has not been completed, the records will be kept in basket marked "Examination incomplete. To return."

21. When it is evident that an examination will never be completed (e. g., if aviator is moved to another station), the history will be filed, not with the completed histories, but in a separate division arranged alphabetically marked "Incomplete. Will not return." A small card (3 by 5) will be made out for such a record and will be filed with the other small cards.

22. Incomplete records on which no rating has been made will not be sent to the Commanding Officer at aviation field nor to the Chief Surgeon, but will be kept by the unit unless the aviator has been transferred when they should be sent to the Mineola Laboratory.

23. Any correspondence relative to an aviator is to be filed with the other reports at Mineola.

DIRECTIONS TO CLINICIAN AS TO CONDUCT OF REBREATHING TEST.

The clinician is to be present throughout the test and is primarily responsible for the subject's condition. It will almost always be possible to keep sufficiently accurate track of the heart action by listening during the eye examination in order to avoid interference

with the psychological test. In case the safety of the subject demands it, however, he should not hesitate to examine the heart more frequently, especially toward the close of the test.

The clinician will be the one to terminate the test by removing the mouthpiece or nose clip. About four times out of five probably this will be at the instance of the psychologist, who will plainly indicate as soon as his results are satisfactory. When this point has been reached the subject is probably within a short space of insensibility and the mouthpiece should be removed without delay.

The clinician may terminate the test before the psychologist has got his full results if he considers that safety demands it, but such an occurrence should be infrequent if proper judgment is used, because any abnormal circulatory condition will give an early psychological effect and it is usually safe to let the test go to this point. An exception is any case of cardiac arrhythmia (except sinus arrhythmia), which increases during the test. In this case the experiment should be terminated very early from the possibility of ventricular fibrillation.

When a definite cardiac lesion can be determined it is unnecessary to prolong the test, for if the clinician's rating is C or D it is a matter of small importance whether the psychologist's rating is A or B.

The physiologist may suggest terminating the test if something is manifestly wrong, as e. g., with the apparatus.

The indications for interference by the clinician are two: First, that he has determined a disqualifying cardiac condition; second, that the subject is on the verge of fainting. To guard against this latter the clinician should carefully watch the pulse and blood-pressure record and should instruct the observer to call his attention at once to any marked change. Blood-pressure readings every minute are desirable toward the end of the test. Subjects who have had an excessive response in pulse and blood pressure, those whose hearts are evidently working too hard throughout the test should be especially carefully watched, but even in these cases it is always safe to allow the test to go on either until the psychologist is satisfied or until there are definite signs of fainting. Rapidity in pulse or moderate increase in blood pressure is not an indication for stopping the test.

The first sign of fainting will be a sudden drop in diastolic pressure, followed latter by a drop in systolic pressure, then a drop in pulse. It is often possible to remove the mouthpiece when the diastolic fall has occurred, but before the other two. A slow and steady decrease in diastolic pressure is to be regarded as normal if not excessive, especially when the systolic pressure is not increasing, but such a steady decline frequently ends with a sudden fall and demands careful watching from minute to minute.

It is highly important to avoid fainting when possible (and even the cerebral type of unconsciousness), though a certain number of cases will faint in spite of the most careful watching; this may occur with great suddenness, especially when coming early in the run.

A middle ground must be taken, giving the psychologist as much opportunity as possible for his observations and yet avoiding disagreeable terminations of the test. As remarked above, the psychologist should terminate the test at least four times out of five.

DIRECTIONS FOR CLINICIAN AS TO RATING.

When a diagnosis of valvular lesion of the heart can be made, no matter how well compensated, the subject should be disqualified. Rarely in the case of a man who has already qualified as a pilot and where the compensation is excellent and the reaction to the test good, he may be passed in class C with explicit directions that he be very carefully watched and be withdrawn later from all air work if he gives any evidence of wearing badly.

Subjects who have or develop arrhythmia are to be rejected (except sinus arrhythmia, which is of no importance).

Subjects who show deterioration of heart sounds (usually due to poor arteries, fatty heart, or flabby heart muscle) should be rejected, or if the deterioration develops late in the test, be rated in class C.

In any of the above cases the experiment should not be prolonged beyond the point where the clinician has fully satisfied himself of an abnormal heart.

The clinician will not be called upon to decide on cases who compensate poorly, since they will receive a low rating from the psychologist, who will demonstrate failure of compensation long before the clinician could. The type of person, however, who because of generally poor constitution fails to compensate at all (no rise in pulse, none in respiration, no change in blood pressure), should be rejected rather than given a low rating. Such cases, however, should be very rarely found in the Aviation Service.

Of the cases who compensate well (probably 75 per cent or more of the experiments) the rating should be based on the amount of circulatory strain involved in maintaining compensation.

It is difficult to establish fixed rules in this regard and much must be left to the judgment of the examiner. Those who become unconscious at less than 8 per cent oxygen without circulatory failure, of course, deserve an A rating. We have passed a few subjects who had a circulatory collapse (either fainting outright or marked drop in diastolic pressure) at less than 8 per cent. Those whose circulation fails between 8 and 10 per cent may be rated B, and those above 10 per cent C. If in doubt, it is safer to give a lower rating, since more fliers will be needed for lower than for higher altitudes, and the

late effects of circulatory strain are always to be considered—i. e., the early development staleness. Rating should be very conservative in cases of high blood pressure. If this is above 150, the rate should be B; if maintained above 160, it should be C, especially when there is evidence of circulatory fatigue. The paragraphs on blood pressure in the directions to the physiologist should be carefully followed.

In cases given a low rating on account of circulatory strain, the fact should be made evident under "recommendation of the board" on the report. Some such phraseology as the following may be employed: "Class C (should not fly above 8,000 feet). Maintains his efficiency at moderate altitudes only at the cost of severe heart strain. Would quickly wear out if used at high altitudes."

NOTES ON THE DIAGNOSIS OF VALVULAR HEART DISEASE.

The cases of valvular disease which the clinician of the research board will have to decide will almost always be difficult to diagnose. This is because the candidates have been already carefully examined and selected.

The rebreathing test is a very efficient aid to the more usual methods of examination, and it may pretty safely be asserted that a man who makes a good run on this apparatus can have no serious cardiac lesion.

Overemphasis must not be placed upon single factors. This is especially true of murmurs. Systolic murmurs are extremely common, especially when heard at the base, in cases where there is no organic disease. Roughnesses of the first sound that suggest a slight thrill are also not uncommon.

A clear prolonged diastolic murmur is, of course, almost certainly caused by either aortic insufficiency or mitral stenosis, but even in this case a diagnosis must not be based on the murmur alone. Evidence of hypertrophy and dilatation, either or both, should be present, and in mitral cases a pretty marked accentuation of the pulmonic second sound. The trained ear learns to judge from the character of the heart sounds rather than the murmurs whether there is organic disease or not, but it is difficult to express in words just what the changes in the heart sounds are which prove decisive.

A heart with an organic lesion seems to behave in one of two ways on the low oxygen test. It may fail to compensate almost from the start; in this case there may be no accentuation of the first sound nor of the murmurs, but rather a deterioration of the sounds and a shortening of the first interval. Such a subject will probably become inefficient very early, will get very blue, and be extremely uncomfortable; a number have themselves removed the mouthpiece saying

they felt that they were suffocating. This type of reaction, indicating poor heart muscle, will be rarely found among aviators.

Much the commoner type of reaction is that of excellent compensation or rather of overcompensation. In this the heart is evidently on a heavy strain from the start, the sounds loud and booming, the apex impulse heaving, second sounds accentuated. Murmurs are sure to come out much more clearly. For a reason which is difficult to understand, this type of case usually runs a high blood pressure, 140 to 160, occasionally even to 180. Psychological efficiency is often held very well.

Such well-compensated hearts frequently hold out and do their work against the odds up to a very high altitude. When a diagnosis of valvular lesion is clear, however, it would be unwise to prolong the test to the point of cardiac failure, as the latter would involve much greater risk than in the case of the normal man.

Numerous cases have been observed where puzzling murmurs have been present on preliminary examination, which did not become stronger during the test, or even disappeared; in these cases the whole course of the test was normal, there was no evidence of cardiac incompetence nor of overstrain. In such a case the murmur should have no weight at all in assigning the final rate.

While we feel very strongly on the danger of flying to a man with valvular disease, there is bound in every case to be bitter disappointment and dissatisfaction with the ruling of the board. For this reason great care must be exercised in the diagnosis and, when possible, two competent clinicians should argue on the matter. Usually it is best to repeat the test to be absolutely sure.

Probably the chief source of doubt will come from cases of poor condition from other causes (bad cold, diarrhea, etc.) with functional murmurs. In some of these cases an interval of two weeks before a retest will clear up the confusion. In the other cases it may be necessary to have a more thorough inquiry into the general condition at the post hospital or even at a base hospital.

In case of doubt it is safe to err on the side of protecting the man, especially when he is a candidate or a cadet. In case of a finished pilot he may be passed in class C when there is a reasonable doubt, but the recommendation of the board should contain explicit directions that his heart must be very carefully watched, and that he is to be withdrawn from flying if trouble develops. The case should be called to the attention of the Flight Surgeon and the man himself should understand the situation thoroughly—both his own condition and the danger of aviation to a defective heart.

ROUTINE EYE EXAMINATION DURING REBREATHING TEST.

1. Instruct the candidate fully as to the methods of procedure during the rebreathing experiment and the signs that he will make to tell you when his vision is blurred, when he is diplopic, etc. It is well to take time to instruct the candidate in this way so that valuable time may not be lost during the experiment, and the psychological reaction disturbed as little as possible.

2. Beginning of sixth minute, after start of rebreathing experiment, note (*a*) convergence near point; (*b*) accommodation near point; (*c*) field of binocular fixation.

3. Note convergence, accommodation, and field of binocular fixation during first 30 seconds of every third minute, and vision every 6 minutes.

4. Make at least one reading after candidate is removed from apparatus.

5. Make note of reason for removing man from rebreathing apparatus on face of card.

6. Note also on face of card whether man is apparently a desirable candidate as far as the eyes are concerned.

7. All records must be in ink.

8. Make all notes on 5 by 8 history card. Loose papers are undesirable.

9. Make a record of the examination in the cross file under heading "Tests and date."

10. As soon as oxygen percentage is recorded, rate the candidate under the date in this manner, on the back of the 5 by 8 card:

(1) 11 per cent (per cent of oxygen at which first permanent change occurs).

(2) 7 per cent (per cent of oxygen where the candidate is ocularly inefficient from any cause). Eye (A).

Thus: 4-20-18. (1) 11 per cent. (2) 7 per cent. Eye (A).

N. B.—Make notes of rating *a*, *b*, *c*, or *d* on card for tests and dates after man's name.

11. As soon as data is complete to this point, enter it on the three copies of the history and make any necessary recommendation, stating why it is made.

(*a*) Under summary of observations during low oxygen tension test, use scientific terms.

(*b*) Under recommendation of board, use lay expressions.

One copy of the history is sent to the Post Commander, one to the Medical Research Laboratory, Hazelhurst Field, Mineola, L. I., and one to Air Service Division, Surgeon General's Office, Washington, D. C.

12. Make certain that the 5 by 8 card which is retained in the laboratory gives a complete statement of the reason why a candidate was rated *a*, *b*, *c*, or *d*, and what recommendations were made as to his final disposition.

13. Keep 4 by 6 cross file up to date, following some such scheme:

Index (cross scheme for Ophthalmological Department).

Card color scheme: (1) yellow, (2) blue, (3) salmon, (4) white.
Subindex under (*a*) Rebreathing.
(*b*) Name and date and altitude in feet where break was first shown.

(1) Men who have flown. FLIERS. (1) Pilot. (*a*) Have flown.
(2) Observer. (*b*) Have not flown.
(2) Acclimated.
(3) Men who show break in accommodation....................ACCOMMODATION.
(4) Men who show break in convergence........................CONVERGENCE.
(5) Men who (do or not) show break after abuse of alcohol, insufficient sleep, sex excess. (*a*) Yes. (*b*) No. ....DISSIPATION.
(6) Muscles..MUSCLES.
(7) Men who show no ocular break..............................NORMAL.
(8) Break in field of fixation..................................FIXATION.
(9) Refractive errors (break or not). (*a*) Yes. (*b*) No. ....REFRACTION.
(10) Men show break in vision. (*a*) Acuity of (*b*) Color (*c*) Field of ....VISION.
(11) Men who (do or not) show break after illness...............ILLNESS.
(12) Men who (do or not) show break after typhoid vaccination. (*a*) Yes. (*b*) No. ....TYPHOID.
(13) Oxygen given during experiment...........................OXYGEN.
(14) Stereoscopic vision...STEREOSCOPE.
(15) Retinal sensitivity. (*a*) Contrast. (*b*) Treshold. ....RETINA.
(16) Tension (Intraocular)....................................TENSION.
(17) Men who have had accidents...............................ACCIDENTS.
(18) Men who are stale...STALENESS.

ROUTINE MONTHLY EXAMINATION OF THE EYE OF THE FLIER (SUGGESTED).

A record of the completed 609 examination should be kept with the papers of each flier, with the additional record of the near point of convergence and muscle strength finding.

1. Visual acuity: If the visual acuity has altered, ophthalmoscopic examination should be made to determine the cause.
2. Examination of the eye.
3. Muscle balance. (*a*) If change in findings, record muscle strength.
4. Near point of accommodation.
5. Near point of convergence.

N. B.—If alteration is found in any of the above findings, stereoscopic vision should be tested.

OPHTHALMOLOGICAL EQUIPMENT FOR BRANCH LABORATORIES.

1. Two small millimeter rules, 15 centimeters in length.
2. One Prince rule. Illiterate " Es " as test object.

3. One 5-foot centimeter rule, marked in millimeters, and in degreees of tangents of arc.
4. One Hare-Marple battery-handle electric ophthalmoscope.
5. Two dozen batteries and three extra lamps for the ophthalmoscope.
6. One stop watch.
7. One Schweiger hand perimeter, with two extra eyepieces, one for monocular use and one for binocular use.
8. Three 75-watt, 110-volt, nitrogen daylight lamps.
9. Two extension brackets, with two shades.
10. One set of visual acuity test cards. (Black's, F. A. Hardy & Co.)
11. Trial case No. 4072, with a multiple Maddox rod and 1½-inch lens.
12. Trial frame No. 4157.
13. One box square prisms No. 4112.
14. Jenning's color-test No. 1.
15. Reeves's wedge.

Per cent transmission and density of average wedge.

Millimeters	5	10	15	20	25	30	35	40	45	50
Density	0.225	0.466	0.70	0.915	1.14	1.39	1.62	1.86	3.085	2.30
Per cent transmission	59.74	34.28	19.84	12.14	7.20	4.06	2.40	1.38	.83	.50
Millimeters	55	60	65	70	75	80	85	90	95	100
Density	2.57	2.785	3.0	3.28	3.485	3.72	3.945	4.18	4.42	4.65
Per cent transmission	.26	.16	.1	.05	.03	.02	.01	.006	.003	.001

16. Two retinoscopes, with an 18 millimeter plane mirror.
17. One 36-watt, 110-volt, frosted bulb, Edison Mazda lamp.
18. One iris diaphragm on stand (deZeng).
19. Opaque shades for examining room.
20. One 5 by 8 filing drawer and 500 No. 1 cards and 500 No. 2 cards, with alphabetical index guides.
21. One 4 by 6 filing drawer, 50 yellow tabbed cards, 100 blue tabbed cards, 150 salmon tabbed cards, and 300 plain white ruled cards.
22. Copy of per cent transmission and density for average wedge.
23. Copy of cross-filing scheme for ophthalmological records.
24. Charts for recording the field of vision, 100.
25. Charts for recording field of binocular fixation, 100.
26. Jaeger test type, 6 sets.
27. Reeves contrast sensitivity test object.
28. One stereoscope and 2–A, 2–B, and 2–C cards.

The board requests that a full report of the work of the branch laboratories be made once a month.

The ophthalmologists at the branch laboratories will be expected to do all the research work possible, keeping the problem of the stale aviator in mind and examining men who have had an accident or are having difficulty in flying or landing. A letter should be sent weekly to the central laboratory at Hazelhurst Field, Mineola, L. I., to the officer in charge of the Ophthalmological Department, reporting the progress of the ophthalmological work, giving details of special examinations made and any suggestions for improving the work.

INSTRUCTIONS TO THE PSYCHOLOGIST.

1. The reactor is given the printed instruction sheet, which he is instructed to read carefully, while care is taken to avoid distracting his attention. During the reading the psychologist should be ready to explain any detail of the apparatus or method in which the reactor may show interest; and after the reactor has finished, the psychologist further explains the procedure and verbally emphasizes the important points in the instruction.

2. As soon as rebreathing commences, the reactor begins to respond to the three sets of stimuli as presented by the apparatus under the manipulation of the psychologist. During the first three minutes of the test the psychologist shall coach the reactor, if necessary, and estimate his comprehension composure (freedom from excitement or nervousness), entering these on the record sheet then or later as good, fair, or poor. He should also note the motor tendencies of the reactor, and if these fall in one or more of the conventional categories, this also should be entered.

In addition to these general tendencies, it is important that the psychologist take notice of the specific tendencies shown by the reactor, and if definite types of error are shown, watch during the succeeding five or six minutes for improvements in these details.

Normally, the test continues until complete inefficiency is reached, at which point the psychologist must sharply notify the responsible medical attendant in order that the reactor may at once be given air, and so prevented from undergoing the collapse which would ensue in a minute or so.

3. The psychologist will record the typical change in the reactor's behavior, using the symbols which are given on the "symbol sheet," so that the recording will interfere as little as possible with the observing. After the test is ended, the entries on the record sheet must be at once completed.

4. Beginning at the sixth minute, and at three-minute intervals thereafter, the psychological work will be stopped for 30 seconds to

allow the ophthalmological and cardiac examination. It is important that the ophthalmologist keep track of the time so that he shall be ready promptly.

5. The psychologist should endeavor tactfully to remind the reactor as to the general conditions of the test, particularly to remove or avoid the impression that the performance required is very difficult. Especial pains should be taken to restore the reactor's composure if he has previously been stirred up by a psychoanalytic or other intimate personal inquisition.

6. All members of the unit must exercise caution that the reactor shall overhear no remarks, serious or jocular, concerning the difficulties, danger, results, or other features of the test which might excite him or cause apprehension or concern. Trivial remarks frequently have a serious effect.

INSTRUCTIONS TO THE PHYSIOLOGIST AS TO THE REBREATHING TEST.

It is the physiologist's duty to provide dependable conditions for a rebreathing experiment. All interpretations of data obtained and the final rating of a candidate require that the oxygen percentage during and at the end of a test be accurately known. The analysis of the air in the tank at the close of a test must be exact. In order to have reliable analysis the gas analysis apparatus must be clean and the samples of air carefully taken.

A perfect experiment requires that the rebreathing machine be in perfect order. Leaks of water and air into and from the machine must be avoided. Water may be flowing into the tank during an experiment through the inlet valve either because it is not perfectly closed or is out of repair. Water may be escaping through the outlet valve for the same reasons. Leaks of air may be due to faulty or improperly closed valves or to loose-fitting mouth parts. Occasionally a candidate may be found who sucks in air and allows it to escape by not keeping his lips closed around the rubber mouthpiece.

The movement of air through the rebreathing machine must be free so that the breathing of the candidate is not hampered. It is necessary to test frequently the resistance offered by the absorption cartridge.

The physiologist is also responsible for the obtaining and the interpretations of all physiological data. These data for the present include the frequency and volume of breathing, the pulse rate, and the three arterial pressures—systolic, diastolic, and pulse.

The respiration data are obtained from the kymograph record of the spirometer's movements. This record is almost valueless if there has been leakage of water or air during an experiment. The calibrating of the spirometer and the drawing of the scale should be

accurate in order that the per minute volume of breathing may be determined with exactness. From the varnished kymograph tracing the volume of breathing per minute is calculated for as many separate minutes as will be found necessary in order to determine the curve of respiration throughout the experiment. The volume of breathing should be calculated by the physiologist and the amount and the time of each minute-volume written down and then handed to the "plotter," who will incorporate them in the final record.

The so-called normal pulse and blood pressures are determined three or four times while subject sits at the machine with nose clip on and mouthpiece in place. These normals should be compared with those of the preliminary pulse rate and blood-pressure study. A psychic influence should be avoided if possible. After rebreathing is begun the pulse rate is counted every minute and the arterial pressures determined every other minute until the eighteenth minute, after which they are taken each minute until the end of the experiment. The O space of the record sheet should be left blank and the determination of the first half minute recorded on the line.

The rule to be followed in making the determinations is to count the pulse rate in the interval between 20 and 40 seconds and to record the count on the half minute. The first count, therefore, will be recorded on the line between 0 and 1. The systolic and diastolic pressures should be determined in the interval between 45 and 15 seconds by the stop-watch and recorded as having been taken on the minute. These should be entered on the record sheet in the space between the lines, the first determination in space 1. This system of recording will make it possible for the "plotter" to indicate the time intervals with exactness on the chart. It is important that the exact time of the termination of the experiment be indicated on the circulation sheet so that the man who plots the record may correctly indicate with a heavy line the time the candidate was taken off.

The physiologist should closely watch the respiration and circulation changes toward the end of the test and should inform the clinician when unfavorable conditions develop.

In order that the ratings may be just to all, the volume of air rebreathed should be large enough to require 30 minutes to reduce the oxygen to 7 per cent. To obtain uniformity in the rate of oxygen reduction the water level in the tank should be varied according to the size of the man to be tested. A larger volume of air is required for a large muscular man and a smaller volume than that used for the average for a small man. The physiologist should decide what level of water in the tank of the rebreathing apparatus is necessary to provide the requisite time for the test. Experience

will soon make it possible to adjust the volume satisfactorily according to the size of the candidate to be tested.

Rating.—When rating a candidate as to physiological responses, take into account the per cent of oxygen reached and the time required for rebreathing. Ordinarily a lower percentage will be tolerated when the fall in oxygen is rapid and the run short than when the fall in oxygen is slow and the time long. If two candidates who both endured down to 7 per cent oxygen, one reaching it in 15 and the other in 30 minutes, are being rated it would be unfair to the man who made the longer run to grade him on the same basis as that of the short run. This is the reason for demanding that all candidates be given a sufficient volume of air for rebreathing to insure a run of 25 to 30 minutes.

In rating take into consideration also compensation in the breathing and circulation. The reaction of respiration will be recorded as poor, fair, good, or excessive. The majority of the men examined have shown at between 8 and 6 per cent of oxygen, an increase of 5.5 liters in the volume of air breathed.

Such an increase is rated good, an increase of 15 or more liters is regarded as excessive. The respiratory response is most marked after 12.5 per cent of oxygen has been reached. The increase in the frequency of the pulse rate for the majority of men who have reacted well has varied between 20 and 40 per minute at about 8 per cent of oxygen. An acceleration of more than 50 may be regarded as excessive. The degree of acceleration is ordinarily slight until the oxygen has fallen to between 13 and 9 per cent, but from these down the acceleration occurs rapidly. The rise in systolic pressure usually is not more than 20 millimeters, a greater rise is considered excessive. A diastolic pressure fall, when it occurs, will be either a slow controlled drop or of the rapid fainting type which is often spoken of as a break in the circulation.

Candidates are rated AA if the compensations are good down to 7 per cent or less and A if good to between 8 and 7 per cent. They are rated B if the compensatory mechanisms show decided insufficiency or failure between 10 and 8 per cent, and C if the failure occurs above 10 per cent oxygen. The physiologist rarely finds reason for placing a candidate in class D. A high systolic pressure, 150 millimeters and above, throughout the greater part of the test disqualifies the candidate for class A no matter whether he compensates well or not.

THE PRELIMINARY PULSE AND BLOOD PRESSURE STUDY.

The candidate reclines for five minutes. The heart rate is then determined by counting the pulse rate by 20-second intervals.

Counting should continue until two successive intervals give the same result. The arterial pressures are then determined. The candidate then stands, the heart rate is counted as before until it reaches a constant rate, when it is recorded, and the blood pressures then taken.

The candidate then raises himself, by placing his right foot on a chair, five times to the standing position on the chair. The pulse rate, with the candidate standing, is immediately counted and as soon as possible thereafter the blood pressures are determined. The candidate stands at ease for two minutes, after which the pulse rate and the blood pressures are again determined.

The purpose of these observations is to determine whether the candidate shows evidences of staleness. In the physically fit the heart rate does not increase much on standing, but in the wearied or physically stale it increases as much as 44 beats per minute. The vasomotor control of the splanchnic area responds to changes in posture. In the fit subject the splanchnic vasotone increases and the blood pressure is raised about 10 millimeters when he moves from the horizontal to the upright standing posture. Weakness is shown by a decrease in blood pressure and at other times by an excessive increase in the heart rate. A great acceleration in the pulse rate following the exercise is also a result of staleness. The systolic pressure should return to normal within two minutes. The subnormal pressure, and the length of time it continues after exercise, has been attributed to lack of condition.

PREPARATION OF THE REBREATHING MACHINE.

(1) Flush the tank to remove all vitiated air. Do this as follows: Close the gate valve under the CO_2 absorber, and also the valve in the return pipe. Open the valve on the spirometer pipe. Open the inlet valve of the water system and allow the tank to fill slowly. When the tank is full, raise and lower the spirometer drum several times to change the air in its dead space.

(2) Fill the tank with new air as follows: Open the gate valves in the air pipes and close the valve in the spirometer pipe. Let the water drain entirely out. Set the valves as before and refill with water a second time. Let drain as before to the desired level.

(3) Set the machine for the start by opening the valves in the air pipes and closing the valve in the spirometer pipe.

(4) Sterilize the mouthpiece by bringing it to the boiling point. See that the corrugated rubber hose is clean and dry.

PREPARATION OF THE RECORDING APPARATUS.

The excursions of the spirometer indicate the depth and rate of breathing of the subject. A fishline connected to the top of the spirometer runs over a pulley and fastens to a counterbalance for

the spirometer can. A writing point is attached to the counterbalance and records the respiration on the smoked drum of the kymograph. The writing point is best cut from celluloid film. The angle of the point should not be less than 60 degrees because very acute points twist easily. The point may be attached to an aluminum stylus by means of beeswax.

A signal magnet, provided with a writing point and connected in series with two cells and a clock interrupter, records equal intervals on the revolving drum—usually half minutes.

SMOKING THE DRUM.

Lay the kymograph paper on the table, glazed side down and glued end away. Hold the drum with the top to the right and lay it across the middle of the paper. Bring both ends of the paper toward each other, letting the glued end overlap. Glue it firmly to the glazed side of the unglued end so that the paper is wrapped tightly around the drum.

Smoke the drum over a 4-inch single-burner oil stove, or a fishtail gas burner. Hold the axis of the drum in each hand and let the drum revolve rapidly toward you, moving the drum from side to side at the same time. Smoke it only until it is coated light brown.

Arrange the drum so that the writing point attached to the spirometer and that of the signal magnet will mark evenly on the drum. The stylus of the signal magnet should be about 1 centimeter above the lower edge of the drum and about 1 centimeter in front of the spirometer stylus.

OPERATION OF THE MACHINE.

Let the subject sit so that the mouthpiece can be held comfortably in the mouth without twisting or pulling in any direction. Close the signal magnet switch. Start the kymograph. See that the valves in the pipes are open and that the gate valve in the spirometer pipe is closed. Put on the nose clip. The physiologist will start the experiment by putting the cork in the mouthpiece at the end of an expiration. The stop watches should be started at this time.

As the experiment progresses the oxygen from the tank is used up progressively. The spirometer stylus will write nearer the top of the drum. Open the inlet valve in the water system and let a little water flow into the tank, sufficient to bring the writing point nearly to the bottom of the drum. Repeat this as often as necessary.

When the experiment is ended close the valves in the air pipes until the air samples are taken.

Write the name of the subject, date, and type of experiment on the smoked drum. It is also convenient to record the oxygen per cent. Remove the paper by cutting through the outer sheet at the lap.

Do not cut through both sheets and scar the drum. Hold the paper by each end, smoked side up, and pass it once through a shellac solution. Hang it up to dry.

CARE OF THE APPARATUS.

Leaks.—If a leak is suspected from the character of the respiration record, first see that the valves of the water system are closed. A leak of water into the tank through the inlet valve will make the lower level of the respiration tracing approach the horizontal. A leak of water out of the tank through the drain valve will make the record approach the perpendicular.

Leaks of air out of the system most frequently occur around the mouthpiece. It may be necessary to tape the rubber portion to the metal part. Leaks of air around plumbing joints may be stopped by using white lead or heavy paint.

The CO_2 absorber.—This is a cylindrical pasteboard carton filled with shell sodium hydroxide. This cartridge is contained in a steel case and is easily replaced. It is effective in removing CO_2 for about 200 to 240 minutes of rebreathing. If the cartridge becomes very warm or the subject breathes excessively do an analysis for CO_2, and if it is present reject the cartridge. Before each experiment the resistance of the cartridge to expired air should be tried by blowing through the cartridge with the air valve below it open and the other valves closed. The spirometer can be easily raised if the sodium hydrate is not caked.

When a new cartridge is inserted, punch both ends full of holes with a pencil, put the loose brass ring inside the lower rim of the pasteboard cartridge, put the rubber gasket around the outside of the lower rim, put the cartridge with the marked end up into the steel case and tighten the thumb screws. Do not use a cartridge without a brass ring and always remove brass ring before rejecting a used cartridge.

Shellac.—Make a saturated solution of powdered shellac and denatured alcohol containing about 1 teaspoonful of castor oil to each 2 quarts of alcohol. The mixture should be shaken thoroughly and a residue of undissolved shellac should always remain in the bottom of the bottle. If the records appear running after shellacing, the solution probably needs more shellac. Do not allow the shellac to stand exposed to the air except while it is being used. The castor oil makes the dried record more flexible.

Kymograph.—The kymograph consists of an aluminum drum revolved by means of a clockwork at its base. The drum slides on a brass sleeve and is held at any desired height by a spring clip. The sleeve ends in a friction plate which rests on a metal disk driven by the clockwork. The sleeve and friction plate revolve about a steel

shaft which passes through both of the heavy plates containing the clockwork and is bolted at the bottom plate. At the top of the sleeve is a screw by means of which the drum and sleeve may be lowered until the friction plate rests upon the metal disk. It is always used in this position when driven by the clockwork.

In the clockwork are a pendulum and a ratchet wheel which provide for a slower speed than can be obtained by any of the fans. It may be thrown in gear by raising the pin in the gear peg out of the hole in which it rests. When the screw near the fan pinion is screwed down the clockwork operates as a medium-spring kymograph. When this screw is up the drum revolves approximately once an hour, which is the speed used for rebreathing work.

CALIBRATION OF THE SPIROMETER.

In order that the volume of air breathed during any period may be determined, the relation between the definite volume of air breathed and a certain linear measure (1 centimeter, for example) on the kymograph must be established.

To calibrate the spirometer, remove the can and fill it with water to a depth of 25 centimeters, measuring with a graduate the amount of water used. If a liter or cubic centimeter measure can not be obtained, use a quart or a pint measure. (One quart equals 1.36 liters; 1 pint equals 0.568 liter; 1 fluid ounce equals 28.66 cubic centimeters.) Divide the volume in cubic centimeters by the depth of the water and the quotient will be the volume contained in the can per centimeter of length. To make the relation scale, let 1 centimeter be equivalent to the volume determined above. This may be attached to the spirometer so that the pointer will pass over the scale on each respiration. Or it may be used for plotting.

THE GAS ANALYZER.

DESCRIPTION OF APPARATUS.

The apparatus consists essentially of a 25 cubic centimeter gas burette with a bulb containing about 17 cubic centimeters and a tube below graduated from 18 to 25 cubic centimeters in 0.02 cubic centimeter, so that it can be read easily to 0.01 cubic centimeter. The lower end of the burette connects with a temperature-control tube similar to the gas burette, but not graduated, and a leveling bottle containing 1 to 2 per cent sulphuric or other acid in 50 per cent alcohol. The top of the burette communicates (by means of a capillary tube) with an absorber for carbon dioxide containing 10 per cent sodium hydroxide, and a similar absorber for oxygen, containing a solution of pyrogallic acid in nearly concentrated potassium hydroxide.

There are four glass stopcocks which must always work freely. A two-way stopcock is situated on a T just above the gas burette by means of which a sample may be taken and a contaminated sample expelled. A one-way stopcock is situated just above the bulb of the control tube and should always be kept closed during an analysis. A one-way stopcock is situated above each of the absorbers and should always be kept closed except when the particular absorber is in use.

Around the two bulbs is a jacket which is filled with water at room temperature. The water in the jacket can be mixed by blowing air through a glass tube passing to the bottom. It is important to keep the water thoroughly mixed in order to insure the same temperature and water-vapor tension in the gas burette and the control tube at the time of an experiment.

USE OF THE APPARATUS.

1. Before an analysis is begun it must be assured that the capillary tubes between the gas burette and the absorbers contain nitrogen. This is the case after an analysis for CO_2 and O_2, and it may be necessary to do an analysis for this purpose.

2. At the beginning of an analysis the level of the sodium hydroxide and the alkaline pyrogallate in the absorbers should be a certain height marked by a wire. The level may be adjusted with all the stopcocks closed, except that to the particular observer in which the level is being adjusted. The leveling bottle is carefully raised or lowered and the stopcocks closed when the meniscus of the fluid comes to the wire, or the wire may be set to the meniscus. After an absorption the level is again adjusted to the wire.

3. The level of the fluid in the control tube is next adjusted. A strip of millimeter paper is pasted on the leveling bottle. The top of the gas burette and the control tube are opened to the outside air. The leveling bottle is lifted a short distance so that the level of the fluid in the control tube comes somewhere between 24 and 25 on the scale of the gas burette. The level of the fluid in the control tube and that in the leveling bottle should be the same, and the point is marked by the sliding wire. The stopcock on the control tube is then closed and kept closed during the remainder of the analysis.

4. The stopcock at the top of the gas burette is open to the outside air and the leveling bottle is lifted until the gas is expelled from the burette and a few drops of fluid run out. The stopcock is then turned so as to communicate with the source of gas, and a sample is then taken by lowering the leveling bottle. The sample may be driven back into the collector several time to insure a representative portion. The stopcock is closed. The time is noted at which the column of fluid falls in the gas burette, and no reading is taken until exactly two minutes have elapsed. This is to insure proper drainage of fluid

from the inside of the tube. If large drops stand on the inside after two minutes the tube needs cleaning.

5. Before reading the volume of the sample, or later, when reading the volume of the residual gas in the burette, the leveling bottle is moved up or down on the control tube until the level of the liquid in the control tube comes to the wire. By means of the millimeter paper strip note is made of the height above or below the meniscus in the control tube at which the bottle must be held to bring the gas in the control tube to its original volume (at the wire). The leveling bottle is then held at the same height above or below the meniscus in the burette and a reading taken. In this way the gas in the burette can always be brought to the correct volume per molecule.

6. The sample is now driven into the CO_2 absorber. (Samples from the rebreathing machine should not contain CO_2, so this step may be omitted and the O_2 absorption carried out directly.) With the leveling bottle above the level of the fluid in the burette, the stopcock above the CO_2 absorber is opened and the bottle lifted in order to drive the sample into the absorber. The gas is driven over eight or ten times, after which the bottle is lowered carefully until the level of the sodium hydroxide in the capillary tube comes up to the wire. The stopcock is closed. A reading of the remaining volume is taken in the usual manner after two minutes. The difference in volume divided by the original volume and multiplied by 100 gives the per cent of CO_2 in the sample.

7. The oxygen absorption is now carried out in a similar manner, the level of the alkaline pyrogallate being brought back to the wire and the stopcock closed before a reading of the residual volume is made. This volume subtracted from the volume remaining after the CO_2 has been absorbed (or from the original volume if the sample is ordinary uncontaminated air) gives the volume of O_2 in the sample, which, when divided by the original volume times 100, gives the per cent of O_2 in the sample.

Example:	Volume of sample	24.00	
	After CO_2 absorption	22.52	
		1.48—	6.17 per cent CO_2
	After O_2 absorption	19.14	
		3.38—	14.08 per cent O_2.

SUMMARY OF THE PROCEDURE FOR AIR ANALYSIS.

1. Be sure that the capillary tube contains nitrogen.

2. Bring the level of the sodium hydroxide and the alkaline pyrogallate in the capillary tubes to their respective wires, or set the wires to the menisci.

3. Set the level of the temperature-control tube.
4. Take the sample.
5. After two minutes read the volume of the sample.
6. Absorb the CO_2. Bring the sodium hydroxide to the wire. Read the volume after two minutes. (Samples from the rebreathing machine do not ordinarily contain CO_2, so this step may be omitted.)
7. Absorb the O_2 and bring the pyrogallate to the wire. Read the volume after two minutes.

CARE OF THE APPARATUS.

Cleaning.—Whenever large drops stand on the inside of the glass burette and temperature-control tubes two or three minutes after the fluid has fallen, it is an indication that the tubes need cleaning. This may be done by drawing cleaning fluid into the tubes. The tubes must first be drained by opening the stopcocks, lowering the leveling bottle and disconnecting it. The fasteners at the top and bottom of the burette should be removed and the rubber disconnected at the top of the burette. This will allow the burette, control tubes, and jacket to be moved forward in the slot as one piece. The lower free ends of the two tubes may then be put in a beaker of cleaning fluid and the solution sucked up by means of rubber tubing attached to the top of the tubes. This solution should stand in the tubes several hours, or even over night. All traces of cleaning fluid are removed by repeatedly filling the tubes with water.

The capillary tubing may be cleaned, after dismounting it, by washing it out with cleaning fluid, rinsing it with water, and drying out with alcohol.

Formula for cleaning fluid.—The cleaning fluid commonly used consists of a strong solution of sulphuric acid in which potassium bichromate is dissolved. A layer of solid bichromate should always be kept in the bottom of the bottle. This solution can be used over and over again.

Stopcocks.—The stopcocks should always work freely, but should never be loose enough to leak. A light layer of vaseline or preferably of a lubrication mixture, should be rubbed on the stopcocks. Too much lubricant is liable to plug the capillary tubes. A good grease is made by melting vaseline and beeswax in the proportions of 3 to 1. Another formula is as follows (Dennis, Gas Analysis, p. 115):

1. Melt together 12 parts by weight of vaseline and 1 part of paraffin. Do not heat enough to give off fumes.

2. Take parts by weight of finely chopped soft black rubber.

Add No. 2 to No. 1 slowly as the latter is dissolved, while heating over a low flame. When most of the rubber is added, test it by pulling it between the thumb and forefinger. When it is of the right consistency it should pull into cobwebby threads.

Rubber connections.—Rubber connection pieces should be removed before cleaning fluid is used. If the rubber sticks to the glass it may be loosened by inserting the point of a penknife between the tube and the glass. A drop of water put under the knife blade sometimes helps. New rubber connections will slip on easily if the end of the glass tubing is moistened with water.

If a leak in the system is suspected, raise the leveling bottle until the sample tube is filled with about 18 cubic centimeters, close all the stopcocks and lower the leveling bottle as far as possible. Readings of the maniscus from time to time will be the same if no leak is present. If the level of the sodium hydroxide and the alkaline pyrogallate in the capillary tubes will not stay at the wire when the stopcocks are closed, either the rubber connections or the stopcocks are leaking.

Red rubber should not be used on the connections where alkali will touch it, as it gives off sulphur, which may finally appear as hydrogen sulphide in the burette.

It may be necessary to make the rubber connections tight. This may be done with a flexible wire, or more conveniently with rubber bands. Loop the band around the rubber tube, pull tight, and wrap the free end around the tube several times, finally passing it under the wrapping with the aid of the curved forceps.

A check on calibration, tightness on joints, and the efficiency of absorbents can be made by analyzing atmospheric air. If the apparatus is properly graduated and in good order, the sum of the oxygen and the carbon dioxide in uncontaminated atmospheric air should be 20.96 per cent.

The scale etched in the burette tube may be made more visible if blue crayon is rubbed on it and a piece of white paper put behind it but not pasted on the burette.

The analyst must remember that the accuracy in the use of the apparatus depends more on making sure that absorptions are complete than upon extreme effort to read the burette as finely as possible. It is essential, therefore, after an absorption is supposedly complete, to pass the gas over again into the absorbent and make another reading to be sure that no change occurs.

Solutions used as absorbents.—A 10 per cent solution of sodium hydroxide is used to absorb CO_2. A 10 per cent solution signifies that in each 100 grams of solution there are 10 grams of the substance dissolved. Weigh out about 10 grams of sodium hydroxide and add water to make 100 cubic centimeters.

The absorbent for oxygen consists of pyrogallic acid in a nearly concentrated potassium hydroxide solution in the proportions of 10 grams of pyrogallic acid in each 100 cubic centimeters of KOH of a specific gravity of 1.55. A hydrometer may be used to make up

the KOH solution, or 767 grams of 1,000 cubic centimeters of water gives a specific gravity of 1.55.

The absorber should be about two-thirds filled with the absorbent, and a one-quarter inch layer of liquid petrolatum should be used to protect the absorbent from the air. One filling with alkaline pyrogallic will last for more than 100 analyses. When the O_2 absorption becomes sluggish, the pyrogallate should be changed, but mere standing in the pipette does not cause it to deteriorate. The pyrogallate should be made more exactly in the manner described, for both weaker and stronger solutions do not absorb so well.

In renewing the sodium hydroxide or the alkaline pyrogallate, care should be taken not to get the oil on the absorbing surfaces. This may be avoided by first removing the oil with a pipette. Or it may be necessary to siphon off the greater part of the old solution through the capillary tube. In this case the lower surface of the oil should not be allowed to come to the lower edge of the absorbing tube. New solution may then be added through the capillary tube and the oil will remain on top and inside of the absorbing tube as before.

It has been found convenient to use in the leveling bottle a 1 per cent to 2 per cent sulphuric-acid solution in 50 per cent ethyl alcohol. The alcohol reduces the surface tension and permits more rapid and thorough drainage. It also acts as a self-cleaner for the burettes.

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